NAVAL REACTOR PROGRAM AND SHIPPINGPORT PROJECT

UNIVERSITY OF MICHIGAN
JUL 1[illegible] 1957
MAIN READING ROOM

HEARINGS

BEFORE

SUBCOMMITTEES OF THE JOINT COMMITTEE ON ATOMIC ENERGY CONGRESS OF THE UNITED STATES

EIGHTY-FIFTH CONGRESS

FIRST SESSION

ON

PROGRESS REPORT ON NAVAL REACTOR PROGRAM AND SHIPPINGPORT PROJECT

MARCH 7 AND APRIL 12, 1957

Printed for the use of the Joint Committee on Atomic Energy

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LETTER OF TRANSMITTAL

CONGRESS OF THE UNITED STATES,
Washington, D. C., June 12, 1957.

Hon. CARL T. DURHAM,
Chairman, Joint Committee on Atomic Energy,
Washington, D. C.

DEAR MR. DURHAM: We would like to thank you for publishing the hearings on naval reactors development held on March 7 and April 12, 1957, by the Research and Development and Military Applications Subcommittees of which we are the chairmen, and ask if you would print this letter as a preamble to the record.

The efforts of the Naval Reactors Branch of the AEC together with its field offices and contractors have given our Nation world leadership in the development of atomic power for naval propulsion. In no other area of military endeavor, either nuclear or conventional, is our national leadership now so clear and pronounced. But today's leadership is not enough. We believe that a fleet of nuclear-powered underwater vessels capable of firing long-range missiles will ultimately decide the balance of world power and the maintenance of the peace.

The Naval Reactors Branch has also played a leading role in the development of civilian atomic power. With its industrial contractors it has been primarily responsible for developing the technology of pressurized-water power reactors. The country has, therefore, received a double dividend on money spent for naval nuclear propulsion. We have world naval leadership in atomic power and will soon have the civilian reactor at Shippingport, Pa. Unquestionably, the dollar value of these developments to American industry is many times greater than the Government's investment.

In our hearings we determined that the Naval Reactors Branch is enjoying the full support and cooperation of the Atomic Energy Commission, and the observations we make below should not be construed as criticism. They are offered in a constructive sense and for the most part call for the continuance of existing practices. We consider the remaining suggestions refinements of existing practices.

We feel confident that our colleagues on the Joint Committee join us in expressing every confidence in the Naval Reactors Branch under the direction of Rear Adm. H. G. Rickover, United States Navy.

In connection with our review of the role and activities of the Naval Reactors Branch, we believe the following observations are appropriate:

1. The wisdom of continuance of the placing of central direction of the program in the Atomic Energy Commission and the Navy in a single official has been amply shown. Our hearings consistently dem-

onstrated that Admiral Rickover has always accepted personal responsibility for the program under his direction—including responsibility for technical setbacks.

2. This unique organizational arrangement whereby the Office of the Chief of Naval Reactors Branch of the Atomic Energy Commission and the Assistant Chief of the Bureau of Ships for Nuclear Propulsion is combined in the same person has prevented much duplication and is in keeping with the purposes of the Atomic Energy Act of 1946 and 1954. The present organizational arrangement for naval reactors work has proved economical, efficient, flexible, and capable of doing the job, and should be maintained. Any suggestion of establishing duplicate functions in the Department of Defense should be rejected in the interests of economy of manpower and appropriated money. The system employed by the Naval Reactors Branch in the selection, training, and assignment of personnel should also be continued. Officers and civilians are assigned to jobs on the basis of ability and not rank. We are assured that the test of selection is—who can best perform the job?

3. The research and development philosophies which have been employed by the Naval Reactors Branch should be maintained. We observed that this approach is neither attached to "beyond the horizons" concepts nor affixed to mere reproductions of successful models. A proper balance has been found in that the developmental goals are fixed at a level above present anticipations of success but not so far beyond them that accomplishment is not possible.

4. The Atomic Energy Commission should consider the immediate assignment to the Naval Reactors Branch of the development and construction of a new civilian reactor concept. With the prospective completion of the pressurized water reactor at Shippingport, additional time and attention could be given to a new reactor type. We specifically call attention to the desirability of assigning the development of an advanced type gas cooled reactor, and point out that some years from now the knowledge acquired in the development of a gas system may have application for ship propulsion.

We were pleased with the assurance we received from the Chief of Naval Operations that Admiral Rickover has direct access to him in connection with the naval reactors effort. We feel sure that in light of the importance of this work that this same access is available to him in all departments in the executive branch of the Government.

We are confident that the Commission and the Navy recognize the importance of these programs in furthering the interest of the national defense and security and will not permit doctrinaire administrative practices to interfere with the effort.

Quite often in carrying out our duties as Members of the Congress we must be critical of the activities of the agencies in the executive branch of the Government. We therefore take great pleasure in commending those who have been responsible for the success of the naval reactors program.

Sincerely yours,

MELVIN PRICE,
Chairman, Subcommittee on Research and Development.
HENRY M. JACKSON,
Chairman, Military Applications Subcommittee.

JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D. C., June 13, 1957.

Senator HENRY M. JACKSON,
Chairman, Military Applications Subcommittee.
Representative MELVIN PRICE,
Chairman, Subcommittee on Research and Development.

DEAR SENATOR JACKSON AND MR. PRICE: I have asked the staff of the Joint Committee to have your letter to me of June 12, 1957, on the naval reactors program printed with the record of your hearings on the subject.

I fully endorse your comments and observations, for the work under Admiral Rickover is most vital to the United States.

Sincerely yours,

CARL DURHAM,
Chairman, Joint Committee on Atomic Energy.

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PROGRESS REPORT ON NAVAL REACTOR PROGRAM AND SHIPPINGPORT PROJECT

THURSDAY, MARCH 7, 1957

CONGRESS OF THE UNITED STATES,
SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT
AND THE SUBCOMMITTEE ON MILITARY APPLICATIONS OF
THE JOINT COMMITTEE ON ATOMIC ENERGY,
Washington, D. C.

The subcommittees met, pursuant to notice, at 2 p. m., in room F–88, the Capitol Building, Hon. Melvin Price presiding.

Present: Representatives Price, Durham, Holifield, Dempsey, Cole, Van Zandt, and Patterson; and Senators Jackson, Hickenlooper, Knowland, and Bricker.

Also present: Willard F. Libby, Commssioner, AEC; Thomas E. Murray, Commissioner, AEC; A. Tammaro, Assistant General Manager for Research and Industrial Development; L. H. Roddis, Jr., Deputy Director, Division of Reactor Development; Adm. H. G. Rickover, Chief, Naval Reactors Branch; Capt. James M. Dunford, Assistant Chief, Naval Reactors Branch; Bryan LaPlante, special assistant to the General Manager; Capt. John H. Morse, Jr., assistant to Mr. Strauss; Capt. W. B. Braun, representing Admiral Burke, United States Navy.

Staff members present: James T. Ramey, executive director; Messrs. Brown, Conway, Hollister, and Toll.

Representative PRICE. The committee will be in order. This is a joint meeting of the Subcommittee on Military Applications, of which Senator Jackson is chairman, and the Subcommittee on Research and Development, of which I am chairman.

The meeting today has been called for the purpose of hearing from the Atomic Energy Commission as to the current status of the projects under the Naval Reactors Branch and what progress we may expect in the future.

It is my understanding that Admiral Rickover is prepared to cover this matter for us and to answer any questions individual members may have.

Admiral Rickover, we would like to say how pleased we are to have you with us today. The committee has been very favorably impressed by the excellent contributions the AEC has made to the civilian power program through the naval reactors program. As Congressman Durham, the chairman of the Joint Committee, has publicly stated in the 202 hearings, the contribution has been outstanding.

We sincerely hope it will continue to be so in the future.

From the large number of models which you have brought with you and which we see in the room, it would appear that you intend

to cover a great deal of material. We will, therefore, turn the meeting over to you, Admiral Rickover, and you may proceed when ready.

STATEMENT OF ADM. H. G. RICKOVER, CHIEF, NAVAL REACTORS BRANCH, ATOMIC ENERGY COMMISSION

Admiral RICKOVER. Thank you, sir. This is the first time I have been at the committee since Carl Hinshaw died, and as a witness who has appeared here many times and who has been questioned by him very pointedly, I would like to express my sincere regrets that he is not with us here today so he could continue to ask so many pointed questions, as he always did.

Although I used to accuse him of being for the Air Force, he was really for everybody, and helped us in the Navy a great deal.

Representative PRICE. We certainly miss him on the committee in many ways.

Admiral RICKOVER. There are a number of activities in the naval program that have no names. I wonder if it would be desirable to name one of these activities after Carl Hinshaw?

Representative PRICE. I think it would be very desirable, and I hope you can find a suitable one to dedicate to his memory.

Admiral RICKOVER. We can find one. I talked to the chairman of the board of Combustion Engineering. They have their new plant at Windsor, Conn., and I think they would be very happy to name it the Carl Hinshaw Laboratory. There are other places too.

If the committee cared that this be pursued, I would be happy to do so.

Representative PRICE. I think the committee would be very happy to have you do it. I think also the first flying prototype of a nuclear aircraft would be a fitting memorial to Mr. Hinshaw.

Admiral RICKOVER. But an aircraft carrier might come first.

Representative PRICE. You may proceed, Admiral, with your presentation.

Admiral RICKOVER. It has been frequently said that the things that have been done in the naval program have been done by a combined industry, AEC, and Navy team. I consider the Joint Congressional Committee to be an additional member of that team. I know and you people know that you have been just as much behind our program as anyone else and I very sincerely feel that way, because I know that without all your help and your confidence during the time when there was not anything to show you, without your backing we would not have progressed as far as we have.

The models I have in this room today are some examples of that, because all of them have either been built or are under construction

I will touch briefly on the naval program and then tell you about some of the advanced things we are doing, as you requested, sir.

The *Nautilus* was refueled about a week ago. She will again be ready for operation in about a month. Her first core ran for 62,500 miles, of which about 37,000 miles were fully submerged. The core lasted longer than we expected.

The new core will last even longer. This additional core life is being obtained without any increase in cost of manufacture, so that in effect when we increase the life of the core we cheapen it; even though it may cost the same it cheapens it in that proportion.

Representative PRICE. Would you mind comparing that performance with the performance of a conventional submarine.

Admiral RICKOVER. Yes, sir. During this process of steaming 62,500 miles, a conventional submarine having equal horsepower would have burned about 2,170,000 gallons of oil, the amount contained in 217 tank cars, with a length 1.7 miles long.

Representative VAN ZANDT. How long?

Admiral RICKOVER. 1.7 miles long; 2,170,000 gallons. That is the equivalent amount of fuel oil a conventional submarine of that power and having the same displacement as the *Nautilus* would have burned. The new core should do better than that.

Representative COLE. What is the price of that?

Admiral RICKOVER. Diesel oil, I think, costs about 8 to 10 cents a gallon, something on the order of 9 cents. I am not absolutely certain of the cost.

Representative VAN ZANDT. Are you good at arithmetic?

Admiral RICKOVER. That would be about $200,000 worth of oil. It is not much in cost. I do not want to leave any impression with this committee that to run a nuclear-powered vessel is cheaper than a conventional one. It is not. Because the amount you save by the oil is insignificant compared to the cost of the reactor core on present prices.

However, the cost of cores is coming down.

I do not want to create any wrong impression on that score.

As I stated, the new core will have more life. We already have evidence of that. As I stated, the *Nautilus* will be ready for sea in April and her core should be good for more than 2 years without refueling.

Representative VAN ZANDT. What did you find on the inside of the reactor, as far as the metals that were employed? I am thinking now of the pipes and so forth.

Admiral RICKOVER. We looked inside the pressure vessel of the *Nautilus* after the core was removed and it was shiny and clean. We found nothing wrong. During the refueling operation no one was irradiated beyond 300 milliroentgens a week, which is the normal permissible by AEC standards—no more irradiation than is allowed in an AEC laboratory for a week. I think 250 milliroentgens was actually the maximum dose.

Representative VAN ZANDT. In the beginning you recall in the design of the *Nautilus* there was piping used that could not take the pressure. I am wondering what did you find in conection with that redesigning?

Admiral RICKOVER. There was no faulty pipe found. A mistake had been made during the building period in 1954. Some wrong pipe had been used in the steam system instead of the pipe which had been specified, but this was corrected before the ship ever went to sea.

At Arco—perhaps I had better talk for a few moments on what we are doing there. We are using that installation as a training facility and as a test facility for trying out new reactor ideas.

For instance, it was there we tried out fuel elements that gave us increased life.

We have trained about 60 officers and about 500 enlisted men on the submarine prototype at Arco. Just before I came up here today,

I heard that we are losing 6 percent per year of all the enlisted men in the nuclear program because they become officers; 20 times as many enlisted men in our program become officers as do in the rest of the Navy.

I am not happy about this loss, but it is good for morale, and it is good for the Navy.

Of course, not all of the credit belongs to our training program. Our selection procedure obtains a high class of people for the program. That helps account for it. It does pose a serious problem to lose so many men, but it results in overall good to the Navy.

Representative VAN ZANDT. What about the initial selection? Have you an unlimited reservoir to select from as far as enlisted personnel is concerned?

Admiral RICKOVER. Enlisted personnel for the program are selected by the forces afloat, but we have fairly strict requirements, such as 4 years obligated service, and graduation from high school. Also a good record and above-average ability and intelligence.

We have, first, a 6 months' course at the submarine school in New London. This is a special course where we teach physics and mathematics, and various nuclear courses. After the course at New London the men are sent to Arco for another half year. There they learn how to operate and service the plant. They are then assigned to nuclear-powered ships.

The officers for the nuclear propulsion program are designated by the Bureau of Naval Personnel. They are also given 6 months' theoretical training and 6 months at Arco. Their course is much more difficult than that the enlisted men. All of the officers and a number of the enlisted men qualify as chief operators before they complete the course. This is a very difficult thing to do, but it assures us of having competent people for our nuclear plants. Admiral Holloway, our Chief of Naval Personnel, has been very farsighted in understanding our problems, and has gone out of his way time and again to help us. Without his help we could not have accomplished what we have.

Representative COLE. How does the enlisted man get to be an officer?

Admiral RICKOVER. The Navy conducts examinations twice a year.

Representative COLE. What additional training does he have in order to become an officer, none?

Admiral RICKOVER. No, sir. When he is selected for officer he is then sent to an officer candidate's school. There he is given special training for about 6 months and, if he completes the course, he is commissioned.

Representative COLE. Is he a general officer, a line officer?

Admiral RICKOVER. Yes, he becomes a line officer, an ensign.

The year's training we give the sailors and officers in our program is very valuable. I have been told that to qualify as Chief Operator at our prototype at Arco is several times as difficult as it is to qualify for command of a submarine.

It requires about 1,000 hours of practical work for this qualification, and this is in addition to all of the study they do. They must become adept in all phases of reactor operation, particularly in everything that pertains to safety. Even the commanding officers work 16 hours a day, 7 days a week at Arco.

I will say no more on training, except I must add that the facility at Arco is most valuable from this standpoint. We have no better training facility in the Navy than we have there and it is absolutely essential for the future of nuclear power in the Navy that we train the people there, on a real plant, a live one, because we do not want any accidents to happen. We want them to know the plant inside out. I am proud of the fact that all of the officers and men in the program are outstanding. They are all a marvelous group of very fine people and I am sure that ultimately they will be the leaders in the Navy.

Senator HICKENLOOPER. May I ask a question of Admiral Rickover?

Do you have a rough approximation of the cost of the operation of the *Nautilus* so far as fuel is concerned? Take the 2,170,000 gallons of fuel oil. That cost compared with the cost of nuclear heat, the core, its replacements, and utility of the core.

Leave out the plant itself.

Admiral RICKOVER. It is rather meaningless to say we are saving money. What we are getting is a profound military advantage.

Senator HICKENLOOPER. I understand that, but I just wanted to get some approximation.

Admiral RICKOVER. This gets into the problem of the cost of atomic power. At the present time, and for the next 10 years, I do not believe atomic power can compete economically with conventional power. We are still in the development stage. We are still learning how to develop and manufacture nuclear cores.

At Shippingport the cost of the power will be between 55 to 65 mills per kilowatt.

I believe it is rather farfetched to expect nuclear power to be competitive with conventional power for the next few years. I do not say it will not happen, but not today, not for the next few years.

Representative VAN ZANDT. What was the cost of the *Nautilus* per kilowatt?

Admiral RICKOVER. In wartime the cost was about 8 cents per kilowatt-hour on a conventional submarine.

Representative VAN ZANDT. You said 8 cents?

Admiral RICKOVER. That is 80 mills. But if you took into account the cost of convoys and fueling stations and other factors, I am not so sure that from an overall standpoint you would find, taking all the other factors into account, that nuclear power on a warship is more expensive than conventional fuel. I am not talking now about the military advantages we get from the use of nuclear power. Nuclear power gives us ships that can go at high speeds and can stay submerged for days at a time.

One of the things we did with the second core at Arco was to run it for 66 days and nights continuously at full power. The lines on this map [indicating] show the distance a nuclear submarine would have steamed under the same circumstances, on a full-power nonstop run. It would have run once around the world and back to New London, and without stopping set out again and go around the world on a northern route. That is a longer continuous run at full power than a plant of any kind, land, sea or air, has ever made. In contrast, the Navy acceptance trial at full power for a new ship is 4 hours. This plant ran for 1,700 hours continuously at full power.

Representative PRICE. Which reactor is that?

Admiral RICKOVER. It is the one at Arco, and is similar to the one that has just been installed in the *Nautilus*.

Representative PRICE. Similar to the *Nautilus?*

Admiral RICKOVER. Similar to the one that has just been placed in the *Nautilus*.

Representative PRICE. The new *Nautilus* reactor?

Admiral RICKOVER. Yes, sir.

Representative VAN ZANDT. The *Nautilus* is equipped with auxiliaries?

Admiral RICKOVER. Yes, sir.

Representative VAN ZANDT. Both diesel as well as batteries?

Admiral RICKOVER. There are two 300-horsepower diesels used for supplying auxiliary power in port. They are capable of propelling the *Nautilus* on the surface at slow speed if the ship had to do so in an emergency.

Representative VAN ZANDT. At any time during her life so far have you had to fall back on your auxiliaries?

Admiral RICKOVER. Yes, sir; we have fallen back on storage batteries for a short time, but Admiral Watkins, who is commander of the Submarine Atlantic Fleet, has told me that the *Nautilus* has operated with as great a reliability as any submarine he has in his entire force. She has not once failed to meet a planned operating commitment.

I understand you are going to have Captain Wilkinson in here next week to testify.

Senator JACKSON. Monday.

Admiral RICKOVER. He will come before Senator Jackson's committee, and I hope you ask him some of these questions.

The *Nautilus*, of course, has operated much more than any conventional submarine since she has been in commission.

Senator JACKSON. In order to get a proper projection of costs on the operation of the *Nautilus*, you would have to project the *Nautilus* into, say, 50 such ships.

Admiral RICKOVER. Yes, sir.

Senator JACKSON. And compare it with 50 conventional submarines with all the supporting elements, would you not, in order to get a fair overall operating cost?

Admiral RICKOVER. Yes, but Senator, you have a lot of intangibles in there, too. A war machine cannot be judged by cost.

Senator JACKSON. No.

Admiral RICKOVER. Cost is one factor. But a more important factor is, What can she do?

Senator JACKSON. In other words, the contribution she can make to our national security.

Admiral RICKOVER. I do not know how you are going to equate the operating cost with the military value.

Senator HICKENLOOPER. My question did not go to holding you down to dollars-and-cents cost. I want to get an approximation of comparison.

Admiral RICKOVER. Would you want me to get this information and file it for the record? I will be glad to.

Senator HICKENLOOPER. If it is at all reliable. I realize there are many, many intangibles involved.

Admiral RICKOVER. Yes, sir.

Senator HICKENLOOPER. You also have an experimental ship and have done a lot of experimenting with this thing, and I presume it would be very difficult indeed to get down to any accurate cost accounting on this thing. I just wanted to get some idea.

Admiral RICKOVER. I think I have given you a rough idea.

Senator HICKENLOOPER. Yes.

Admiral RICKOVER. I think the best way to sum it up is to state that the *Nautilus* is not a new type submarine; she is really a new weapon. I think you just cannot compare it with any conventional submarine. You would be comparing two dissimilar things. It is very difficult for most people, including people in the Navy, to realize, that a nuclear submarine is really a new weapon. We are going to be faced with the same problem in the Navy when we get the first nuclear-powered surface ship.

The next class of submarine after the *Nautilus* was the 578 class. This model [indicating] shows the *Nautilus*. It is 320 feet long and makes over 20 knots. It displaces 3,200 tons on the surface.

There are five of the 578 class. Four will be attack submarines and the fifth one will be a guided-missile submarine which is now being built at the Mare Island Naval Shipyard. Keels of all five have been laid. The first one, the *Skate*, will be launched in May at Electric Boat, and should be at sea about the end of this year or early next year.

This one [indicating] the *Skipjack*, is the latest type, with an *Albacore*-type hull. It has a single propeller.

The reason we went to a faster submarine was because soon after the *Nautilus* went out on her trials it became evident that for a submarine to remain effective against the most modern type of antisubmarine methods, she would have to make higher speeds.

Therefore, we designed this ship and she should be in operation about June of 1958.

Incidentally, the *Sea Wolf* went to sea this morning at 8 o'clock. Perhaps you would want to hear about the *Sea Wolf?*

Representative PRICE. Yes.

Admiral RICKOVER. I will get on that story now. I hope you do not mind me jumping around on this testimony.

Representative DURHAM. I would like to hear about the *Sea Wolf*.

Admiral RICKOVER. As you know, the *Sea Wolf* reactor uses sodium as a coolant instead of the ordinary water used in the *Nautilus* reactor. Sodium becomes about 30,000 times as radioactive as water. Furthermore, sodium has a half-life of 14.7 hours, while water has a half-life of about 8 seconds. As we went on with the testing of the *Sea Wolf* we found that even a very small leak in the heat exchangers would cause serious trouble. We went to full power on the *Sea Wolf* alongside the dock on August 20 of last year. Shortly thereafter she developed a small leak. It took us 3 months, working 24 hours a day, to locate and correct the leak. This is one of the serious difficulties in sodium plants. When you do have trouble, a considerable amount of time and expense is involved in correcting it because of the high radioactivity. We found that the trouble was a type of corrosion of stainless steel called stress corrosion; stainless steel has a tendency to become corroded by sodium. This means that unless the heat exchangers are absolutely tight and never leak there will be trouble.

We managed finally to fix the heat exchangers on the *Sea Wolf*.

We cut out some of the heat exchanger capacity which reduced the power about 10 percent. We also cut the superheaters out of the system which reduced the power another 10 percent. The *Sea Wolf* went to sea on the 21st of January, and she has been operating since that time. With the reduced power she makes about 90-percent speed.

I was on her during her first sea trials. She steamed about 800 miles, half of which were submerged. After operating for 4 or 5 days she went into drydock for structural repairs. This had nothing to do with the atomic powerplant. She got out of drydock and was at sea again for 8 to 10 days.

If a leak develops in a sodium plant on board ship—I am not talking about shore sodium-cooled plants—then it is quite serious to repair. The radioactivity must be left to decay, and repairs are lengthy and expensive.

But if you had a thimbleful of leakage in a sodium plant you probably could not run.

Senator BRICKER. What is the reason for adopting the sodium coolant?

Admiral RICKOVER. At the time we started on the nuclear propulsion program, sir, we went to two equivalent approaches. At that time, in 1947, we did not know which one would work. As a matter of fact, at that time we thought sodium had a better chance of working than water. Sodium had been chosen by General Electric for their power breeder at the Knolls Atomic Power Laboratory. Later on, when the Commission found that the design of the sodium-cooled power breeder was not going along well and the expense to build it would be too great, it was changed to a naval submarine project and we in the Naval Reactors Branch took it over.

No one knew at that time which would work better, and since atomic power was extremely important for the Navy we decided to follow the two approaches, but we did not know then which would be better. In fact, we were not then definitely sure that either one would work. Now that we have had the chance to operate both the *Nautilus* with her water-cooled plant, and the *Sea Wolf* with her sodium-cooled plant, it is obvious that water is much better than sodium for naval plants. All other nuclear ships, submarines and surface vessels, are being designed for water-cooled plants.

Senator BRICKER. What did you say the half life of sodium is?

Admiral RICKOVER. 14.7 hours.

Representative VAN ZANDT. What percentage of pressure have you lost?

Admiral RICKOVER. We have not lost pressure. We have lost heat transfer capacity. We have lost about 20 percent. The bypassing of the superheaters and the plugging of some of the heat exchanger circuits have reduced the heat transfer by about 20 percent.

Representative VAN ZANDT. Then you are working with 80 percent of capacity today.

Admiral RICKOVER. Yes, sir. But if we get more leaks we will have to plug additional circuits, and reduce the capacity some more.

Representative VAN ZANDT. What has that done to the speed?

Admiral RICKOVER. It has cut the speed 2 to 3 knots so far. Of course, the speed of a ship is not cut in proportion to the loss in power.

Senator Bricker, I think you have to recognize that if you want to get ahead with any game of this kind you have to take a chance. You do not know if it will work and if something is important you have to go ahead on more than one. You went ahead fully, experimentally, on both sides.

Admiral RICKOVER. Yes, sir. I did not consider the *Nautilus* a success until it was demonstrated that it worked all right for a long period of time.

Senator BRICKER. Is there any advantage in the sodium coolant at the present time that you know of?

Admiral RICKOVER. Theoretically sodium has advantages which may pay off in shore plants. You can get much higher temperatures and steam pressures, which means greater efficiency. Also it is possible to use lower pressures to circulate the sodium in the primary system. This means less pumping power.

For example, in the *Nautilus* we use high pressure in the primary system in order to keep the water as a liquid instead of boiling over into steam. On the *Sea Wolf* we use low pressure, just enough to force the sodium through the system. For this reason the pumping power in the *Sea Wolf* is only one-fourth that in the *Nautilus*.

Sodium has the advantage that it does not rust away the surface of material as water does. For this reason small particles of radioactive material do not get into the system and remain there for longer periods of time, and make access and maintenance difficult.

There may be advantages for sodium for shore-based atomic power-plants but I cannot see it for a ship. It is too dangerous for a ship.

After the *Sea Wolf* returned from her first trials she was docked at the Electric Boat Co. We then moored a conventional submarine alongside her and flooded the latter's ballast tanks to see how much of the *Sea Wolf's* radiation would carry through the flooded ballast tanks and into the ship. Even with the ballast tanks full, enough irradiation came through to the conventional submarine to give her crew in that vicinity as much radiation in 4 hours as is normally permitted for a week. Of course, in a while the radiation would be reduced a great deal because it has a half-life of 14.7 hours.

These are some practical problems we have learned about sodium plants. I am not saying these all apply to shore-based sodium plants. I am confining myself to ships. It certainly does apply to ships. As a result of this situation on the *Sea Wolf* and because the Navy is not building any more sodium-cooled ships, the Commission has decided to shut down the Mark A prototype plant at West Milton, N. Y. In order to save money, we are shutting it down. There is a letter in process which states this, but which may not yet have reached the committee.

Representative DURHAM. The letter has been received today.

Admiral RICKOVER. I wanted to mention it.

Senator BRICKER. That will be the only sodium reactor, then, in the whole fleet of submarines.

Admiral RICKOVER. Yes, sir. We intend to keep on operating the *Sea Wolf* as long as we can. If we get another sodium leak we will analyze it and see how expensive it is going to be to repair it. If it is not too expensive we will repair it and keep on operating because we can get very valuable tactical information today from any nuclear-

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powered ship. We are not planning to have any more sodium-cooled ships in the Navy at the present time.

Representative VAN ZANDT. Have you had any personnel problems as far as exposures?

Admiral RICKOVER. No, sir. The maximum exposure we have had in the *Nautilus* per year in 2 years of operation is about 2 roentgens. That is the total for the year. The average radiation of people in the *Nautilus* during the 2 years of operation has been about 200 milliroentgens a week, or two-thirds of what is permissible in AEC laboratories.

Representative DURHAM. That West Milton plant could be used for civilian power; could it not?

Admiral RICKOVER. Actually, since it first started up we have gotten out of that plant about 2¼ million kilowatts of electric energy, of which about three-fourths of a million was sent out over the Niagara-Mohawk system. The rest was used on the site. But there is not much income from the sale of this power, sir. The cost of operating the plant is pretty high. That is, you get a few thousand dollars for the power but it costs very much more to operate. That is not a good financial deal for the Government.

Representative PRICE. It is not a good prototype for a civilian reactor.

Admiral RICKOVER. No, sir; because a civilian reactor would use an entirely different type of heat exchangers and an entirely different reactor system. A civilian plant would also be much larger. We are expecting to use the sphere in which the *Sea Wolf* prototype is contained for a destroyer prototype. I will discuss this in a little while.

Senator JACKSON. While on reactors, what about the gas-cooled reactor; what is the situation there?

Admiral RICKOVER. For a naval vessel?

Senator JACKSON. For propulsion.

Admiral RICKOVER. We made studies of gas-cooled reactors in the early days before we decided on sodium or water or gas, and we came to the conclusion first that a gas plant would be heavier and take up more space, and second, there was no assurance that there would not be leakage of radioactive gas into the ship. You may be able to tolerate such leakage in a shore plant. Since we do not know yet how to make any gas system tight, I do not consider it practicable for a ship. You are always taking the chance that radioactive particles may carry over from the reactor into the propulsion system or that radioactive gas leaks into the atmosphere. You can irradiate the crew this way.

A plant using air as the coolant would be so large it is impracticable for a warship where space is limited. Therefore, you have to go to a closed cycle plant. This type of plant should be tried out ashore and on other types of ships before it is tried in a naval vessel.

The Maritime Commission and the Reactor Development Division are having studies made at the present time of gas-cooled reactors for marine application. My personal opinion is that it will take a number of years before there is a sufficient degree of reliability to permit us to go ahead with a closed cycle gas-cooled plant in a naval vessel.

You see, our program consists not alone of reactors but also of ships that are appropriated for by Congress and we have to meet a date, and

ships have to work. That is a difficulty I labor under. That is demonstrated by all of these models. Everything you see here either has been built or is being built. They are not pictures of reactors. They are items that have been or are being designed.

Representative PRICE. Admiral, it would be advisable if you would just specifically describe to us the different types of reactor programs you are engaged in at the present time and then we might direct our questions toward those various types of reactors that you are actually working on.

Admiral RICKOVER. Yes, sir.

Representative PRICE. And then discuss those you think might be valuable to put into future programs.

Admiral RICKOVER. I discussed the Nautilus and the Seawolf. I would like to go on because I have so much more to say. I have talked about the 578 class. There are four 578-class attack submarines and one guided missile submarine.

These are the 585 class [indicating], which are single screw. There is 1 in the 1956 shipbuilding program and 6 in the 1957 shipbuilding program.

Incidentally, it may interest you to know this: I just checked up the amount of kilowatts we are going to have in nuclear-powered ships in the Navy. Projecting the present rate of nuclear shipbuilding we would have by 1963 about 1½ million kilowatts of power in operation and an additional million kilowatts in ships under construction. So we might have either in operation or under construction by 1963 about 2½ million kilowatts of atomic power in the Navy.

Senator JACKSON. 600,000 more than Grand Coulee.

Admiral RICKOVER. Yes, sir.

Representative VAN ZANDT. What is the mission of the Albacore type?

Admiral RICKOVER. It is an attack submarine. It can carry standard torpedoes. But its nuclear plant can also be used for guided-missile submarines; there will be three in the 1958 program. There are also two other types of nuclear submarines.

One type, and the one I consider very important, is the radar picket submarine. The reactor plant is being designed by the Knolls Atomic Power Laboratory of the General Electric Co. It will have two reactors. The submarine will displace about 5,800 tons on the surface and 8,000 tons submerged. It will be by far the largest submarine ever built.

Representative DURHAM. Is there any difficulty in procuring the raw material?

Admiral RICKOVER. Yes, sir. You mean fissionable material?

Representative DURHAM. Not only that—zirconium.

Admiral RICKOVER. I am glad you mentioned that. I might as well say right now and get into that—in order to carry this naval program through we have had to build up an industry. The first type of industry we have had to build up is zirconium. We started several years ago when the Atomic Energy Commission made a contract under competitive bidding and selected the one which offered the best terms, Carborundum Co. They contracted to supply 325,000 pounds of sponge zirconium a year for 5 years at a cost of about $12½ a pound.

Last year in looking into our prospective program we decided that by late 1958 we would have to have enough additional zirconium

sponge-making facilities for 2 million pounds of sponge a year. An arrangement was worked out between the Navy Department and the Atomic Energy Commission whereby the Atomic Energy Commission made the contracts, the Navy supplied the money, and we brought three new organizations into the program. They were selected on the basis of competitive bidding to see which ones offered contracts which were to the best financial interests of the Government. One of those brought in was the National Distillers Corp. They are putting up their own plant and developing their own process to make a million pounds of zirconium sponge a year for us.

The National Research Corp., is another contractor with whom we made a 5-year contract. I think they are building facilities to make a minimum of 700,000 pounds a year for us by still another process.

We made another contract with the Carborundum Co. to supply us from another plant which would produce for us about 600,000 pounds a year for 5 years. In addition to these contracts we made one contract with the Wah Chang Corp. to operate the Government-owned pilot plant we had at the Bureau of Mines in Albany, Oreg. Still another source of supply is the Hugo Neu Co. from whom we expect to get Japanese zirconium. We expect to get zirconium sponge under our new contracts for about $6 to $7 a pound, instead of about $12 as at present.

The companies who have these contracts, in addition to putting in enough facilities for carrying out the naval program, are also putting in capacity to take care of anticipated civilian reactor needs. We paid $300 a pound for sponge when we started out in 1948. It was only available in gram quantities at that time.

Senator BRICKER. What are the civilian uses?

Admiral RICKOVER. In addition to reactor use, it is used in the electronic industry for clearing out air and gases and so on in electronic equipment. It certainly will be used in civilian atomic powerplants, because a number of the organizations who are designing atomic powerplants are using zirconium as a basic construction material.

It also should find considerable use in the chemical industry because zirconium is much less corrosive than stainless steel at higher temperatures. It is far better.

Representative DURHAM. Does your program take the entire production from the companies you mentioned?

Admiral RICKOVER. It is currently taking nearly all of the entire production. But, as I said, the new companies are installing capacity to meet the naval requirements, and also other reactor requirements, as well as various commercial uses. But we are paying for our requirements. The other people who are designing reactors which use zirconium have not put up any money, as far as I know, to get the zirconium they will need. The Navy has put up its own money for this. The money comes from naval construction funds.

Representative DURHAM. In other words, the civilian reactors cannot depend on this production.

Admiral RICKOVER. These companies are building more capacity than is needed for the naval plants, so there should be zirconium available for civilian reactor plants.

It might interest you to know that in every one of these cases the companies put up their own money for their plants. We did not finance their plants; we did not recommend that they get a certificate of necessity. The contracts were made on a strictly commercial basis. From here on out we expect to be able to buy zirconium in the regular market.

The next important thing we had to do was to get more facilities for making reactor cores.

Our practice right now is to have our laboratories develop and make the first core of a type, and thereafter to put it out on competitive bidding.

For example, take the core for the 578-class submarines. About 8 months ago we asked for competitive bids for 5 of these cores. We now have a number of companies that have equipped themselves at their own expense to manufacture cores on a competitive basis: Westinghouse Electric Corp.; Olin-Matheson Co. at New Haven, Conn.; Metals & Controls Corp. at Attleboro, Mass.; Combustion Engineering Co. at Windsor, Conn.; and Babcock & Wilcox Co. at Roanoke, Va. Each company has put in at least $3 million of their own money, again with no certificate of necessity, for the necessary facilities. They have taken contracts for these cores on a competitive basis. On this basis we were able to order these cores for less cost.

We have just put out proposals for seven cores for another type of submarine. These will all follow the design of the first one, which is a developmental job, and which was designed and built at the Bettis Laboratory. All will be made in commercial facilities and competitively. We are getting industry to make as many other components as possible for our nuclear plants.

So that even as we are going along with the design of different types of plants we are establishing the industry necessary to carry the production along.

Insofar as components for nuclear powerplants for these ships are concerned—I looked this up just the other day—we have placed orders for $29 million for nuclear parts competitively—this is about 86 percent of what we are buying now on competitive lump-sum bidding, and only 14 percent is bought on cost-plus basis. This consists of items such as controls where the development is still in progress and sources of supply have not yet been developed. I am not talking about the steam machinery. That is all bought competitively. I am talking about the nuclear part. Even for the nuclear parts of the plant 86 percent is being put out on competitive bidding right now.

Representative HOLIFIELD. Private companies are doing it?

Admiral RICKOVER. Yes, sir; private companies are doing it. We do not want laboratories or plants operated by the Government to do it. We do not want to keep on building up Government's facilities. Private industry is doing it. I think you would be amazed if you really knew how extensive this private manufacture has grown.

Representative DURHAM. Do you think they are qualified?

Admiral RICKOVER. Yes, sir; we have taught them and supervised them, and we have had them send their people into places such as Bettis and the Knolls Laboratory where they are taught how to do it. Our people teach them how to do it. We help them set up their factories. We start them off by having them make small pieces. Before we assign them contracts for large items we assure ourselves that

they are capable of doing it. I do not have much concern about this at all.

Representative HOLIFIELD. Do you have any trouble getting private companies to bid on these different components?

Admiral RICKOVER. Not on reactor cores. We have difficulty with things like valves because they, as well as many other items, are very special. They have to be made leak tight, and they require a great deal of engineering. As long as we have an economy where people can get lots of business by doing conventional stuff not too many want to get into this special field. More companies would rather use their engineering staffs on conventional items because they can make more money that way. But those who look to the future know that this is good business to learn the new techniques which are going to be necessary if they are to remain competitive tomorrow. It is these forward-looking ones who are getting into our business. We have really had to fight with people in many cases to take our orders. It has not been easy.

Representative PATTERSON. Who pays for tooling on special valves?

Admiral RICKOVER. They do. We are trying to get this program into industry as fast as possible—to buy it like a loaf of bread.

Representative PATTERSON. You could not expect any manufacturer to put a special gear into a plant where he is going to make only 200 or 300 or probably even 2.

Admiral RICKOVER. Yes, sir; I do.

Representative PATTERSON. You expect him to do that?

Admiral RICKOVER. Yes, sir.

Representative PATTERSON. And have them pay for the tooling?

Admiral RICKOVER. Yes, sir. Sure. Why not?

Representative PRICE. Are they doing it extensively?

Admiral RICKOVER. Yes, they are.

Representative HOLIFIELD. Do they do it at a loss to themselves?

Admiral RICKOVER. Look, next year we are going to have about $50 million worth of reactor core business alone. It is like a fuel business. Once you get a ship in the water with a core you have got it there 3 or 4 years, then you have to take the core out and put a new one in. It is like the oil business.

Representative PATTERSON. Then do you go back to the original vendor you did business with——

Admiral RICKOVER. Competitive bidding.

Representative PATTERSON. Again?

Admiral RICKOVER. Mr. Patterson, that is what I thought Congress wanted us to do.

Representative PATTERSON. I am just asking the question. If you can get them to do it, fine, but I do not see how you can get the manufacturer to do that.

Admiral RICKOVER. We do.

Representative HOLIFIELD. They include the cost of that.

Admiral RICKOVER. Sure. It is going to be charged off. They have to charge it off over a reasonable period of time just as they do on any other venture, but I think we have babied a lot of people in this country too long with the glamor of atomic energy, and I think as soon as possible we have got to get down to do it like any other business.

Representative VAN ZANDT. Can we talk about some dollars and cents here?

Admiral RICKOVER. Yes. May I take a few minutes for the other ship?

Representative PRICE. Did you cover each one of your individual programs that you are working on? Can you cover that specifically and then we will ask questions?

Admiral RICKOVER. Yes, sir, in only a short time.

I have covered these three types of submarines and the large radar picket submarine—which can operate either as a surface ship or as a submarine. It is designed to go along with a carrier task force.

Representative COLE. Why do you have two reactors?

Admiral RICKOVER. In the first place, if there were only one you would have quite a large monster, and if that one went out you would have a valuable ship which costs more than $100 million in a helpless condition.

It is like any other important ship; you install more than one plant. The two plants are exact duplicates.

Representative VAN ZANDT. Is that an exorbitant cost?

Admiral RICKOVER. It is a high cost, but it is for the first one. Follow ships will be cheaper. I will give you the cost of every one of these ships in a moment, sir.

The last type nuclear submarine plant we are designing is for a hunter-killer submarine, a type which we could use in large numbers.

This represents another departure from our previous practice. Combustion Engineering has put up their own money for all of their facilities at their Windsor Laboratory. Not a penny of Government money has been used in their laboratory facilities. They have built and paid for all their own critical experiments. They have not only done all these things at a cost of about $10 million, but they have also put up $3 million of their own money to assist in the research and development of this submarine project. The prototype for this plant is now being built on land which Combustion Engineering has let us use near their laboratory at Windsor, Conn.

The Electric Boat Co. is building the prototype for Combustion Engineering, and there is a corresponding submarine in the 1958 shipbuilding program. We are building as small a reactor as we can for this horsepower to keep the ship small. It will be as quiet as possible. I have now covered all of the nuclear submarine types.

There are three other types of ships—surface ships. First we have the aircraft carrier, for which Congress last year authorized the Navy to start buying the machinery—about $21 million to start manufacture of both the conventional and the nuclear machinery.

The nuclear-powered aircraft carrier will have 8 reactors, 2 reactors per shaft. The old battleships such as the *California* and the *West Virginia* developed 32,000 shaft horsepower or about 22,000 kilowatts altogether. This ship will have an auxiliary plant which will use more power than the main propulsion plants of the battleships of the last World War.

I am not going into the military characteristics of the carrier. I am sure Admiral Burke, when he testifies, will do a better job on that than I can. I will just talk about the technical aspects. As I mentioned before, the Navy expects to ask for one of these each year, starting with the 1958 shipbuilding program.

Another surface nuclear powered ship is the cruiser. This is the one which Secretary of the Navy Thomas recently named the *Long Beach*. It will displace about 14,000 tons. It will carry a considerable number of guided missiles.

It uses, in general, the same type of reactor as the aircraft carrier. There will be two reactors in this cruiser. The keel for the *Long Beach* will be laid in less than a year, and she should be completed late in 1960. This ship is being designed, and will be built at the Quincy, Mass., shipbuilding yard of the Bethlehem Steel Co. The reactors are being designed at the Bettis plant of the Westinghouse Electric Corp.

The last ship in the program is a frigate.

At the present time the Navy is mostly depending on destroyers for antisubmarine warfare, but our destroyers when they make high speeds, have to be refueled at short intervals. This creates an intolerable situation because they cannot carry enough fuel to operate for adequate periods of time at high speeds without refueling. We found that out when we sent the *Nautilus* out to be attacked by the destroyers. The destroyers would go out and operate with the *Nautilus* and have to go back to port to refuel if they ran at full speed too long a time.

The AEC has assigned a project to the Knolls Atomic Power Laboratory to develop a powerplant for a frigate. We are trying to design the machinery plant with as low a weight as possible. Work on the frigate reactor design has just been started. I am not sure whether the committee has as yet been notified about it.

Mr. RODDIS. I do not think the letter is here yet.

Admiral RICKOVER. Possibly it has not gone out of the Commission yet.

To sum up, the Navy's nuclear propulsion program consists of the *Nautilus* and the *Sea Wolf* which are experimental types. Then we have the 578 class plant. Following that one we have the *Albacore* hull type which can be used either in an attack submarine or in a guided-missile submarine. Next there is the radar picket submarine which can accompany a carrier task force, and finally there is the hunter-killer submarine. For surface ships there are the three types: aircraft carrier, cruiser, and frigate.

So with the types of nuclear propulsion plants we are now working on we envisage being able to power any important naval vessel. This can be accomplished by using one or more of the reactor plants I have described. We are right in the middle of a vast program for changing our Navy.

A most important submarine is the one with two reactors. Its propulsion plant can also be used for large submarines carrying ballistic missiles. In fact, we had this in mind from the very first. It was changed over from the original concept of a missile-carrying submarine to a radar picket submarine because the submariners did not like it. They were not smart enough then to see the possibilities of such a submarine, and so they did not back it. But the surface ship people saw its utility, and backed it. That briefly describes our program.

I have mentioned the fact that we are getting industry into our program, and I should like to elaborate on that.

Representative VAN ZANDT. The Congress appropriates, do they not, to the Navy and its shipbuilding program for this nuclear powered construction; is that right?

Admiral RICKOVER. Yes, sir.

Representative VAN ZANDT. Is that money positively spent on the nuclear powered ships?

Admiral RICKOVER. Yes, sir.

Representative VAN ZANDT. Can it be diverted?

Admiral RICKOVER. No. The Navy really wants atomic powered submarines and the Navy definitely does not divert any money from nuclear submarines.

Representative VAN ZANDT. A few years ago surely they had a tendency to divert some of this money to conventional type construction. Now is it different?

Admiral RICKOVER. It is different now. The thing that holds us up from going even further in nuclear power in the Navy is that we have got to prove some of these designs. You people always ask the question, "Why do you build any other ships, now that you have the nuclear power?"

You have to put yourself in Admiral Burke's place. He has commitments he must meet today in the Near East, and he has not got the fine nuclear-powered ships. He has got to have ships today; he cannot just obligate all his construction money on the nuclear-power program. Perhaps a generation from today everybody will say, "They were damn fools for not having done it," but the people who may say that will not have been faced with the problems that we are faced with, those of us who have some responsibility are faced with.

Representative VAN ZANDT. From an operational standpoint, when will the nuclear-powered ships start to phase into the fleet?

Admiral RICKOVER. The *Nautilus* and *Sea Wolf* are now at sea. The first one of the 578 class submarines will be completed about the end of this year. After that there will be a new ship about every 6 months. About 3 submarines should be out in 1958. As you know, a total of 15 submarines have been authorized for construction. I should mention that we have also spread the base for ship construction for nuclear-powered ships. We now have two more commercial submarine building yards besides Electric Boat.

The Ingalls Shipbuilding Corp., in Pascagoula, Miss., and the Newport News Shipbuilding & Dry Dock Co. have been awarded contracts for building nuclear-powered submarines. This is a very fine thing because we will now have three commercial shipyards to build nuclear-powered submarines. Since there will be a large number of nuclear-powered submarines, we will be able to increase the design talent available. It will also give us an opportunity to get competitive bidding on submarines instead of always going on a negotiated basis or on a cost-plus-fixed-fee basis. In fact, the first nuclear submarine contracts awarded to Ingalls and Newport News were on a fixed-price basis.

So, you see, we are trying, as far as possible to get out of the system we have been using of paying a man whatever it costs him to do the job; instead to give him an incentive for doing it efficiently.

Representative PRICE. Are you on a competitive-bid basis now on the allocation of submarine contracts?

Admiral RICKOVER. Yes, sir. The last 4 nuclear-powered submarines were awarded, 1 to Electric Boat, 1 to Newport News, and 2 to Ingalls. The three companies submitted bids, and the submarines were awarded on a fixed-price basis. It is not yet 100 percent pure competition, sir, but pretty close to it.

In a fixed price, the Navy, I think, paid roughly about $40 million per submarine.

Representative DURHAM. Has there been any cutback on the program?

Admiral RICKOVER. No, sir.

Admiral RICKOVER. There were six in the 1957 program. There will be four in the 1958 program.

Representative PRICE. I know only four are proposed in the 1958 program.

Admiral RICKOVER. Only four are proposed in the 1958 program. That is correct, sir.

Representative PRICE. Has there been any cutback financially to your program.

Admiral RICKOVER. Well, I have not gotten as much money as I could use, but I think any witness you get up here would tell you that.

Representative PRICE. Did you get what you asked for?

Admiral RICKOVER. I got what I asked for from the Commission. I did not from the Navy. I get only a small portion of my development money from the Navy. I think you understand that without the support of the Atomic Energy Commission, and the freedom with which we can operate in the AEC, we would not have any nuclear-powered naval vessels today. The AEC budget contains all that I asked for this year. However, the naval program is advancing so rapidly that it appears now we could use 9 to 9½ million dollars more of AEC funds.

I want to make it clear that the Commission has budgeted for the money I asked. I do not want any misunderstanding on that score.

Representative COLE. Why did you say the Navy would not?

Admiral RICKOVER. The Navy in the early days did not put much money into the program. They are still not putting in as much money as I need.

Representative COLE. So many ships in that many years does not look like that.

Admiral RICKOVER. I am talking about research and development funds, not construction funds. Today in fiscal 1958 I am getting $86 million from the Atomic Energy Commission in research and development. I am getting about $11 million from the Navy. I tried to get $20 million from the Navy and could not, and that set us behind.

Senator JACKSON. You were cut almost $10 million.

Admiral RICKOVER. I was cut about $7 million in the Navy. I mentioned this to Admiral Burke the other day. He is going to help us as much as possible. But you realize that our major support in research and development comes from the AEC. Furthermore, no one else has as fine a committee to deal with as you people. I mean that. I am not just joking. Your committee has been a great support. Without this committee the Atomic Energy Commission could not possibly fare as well as they have, nor could the naval program have fared as well.

Representative COLE. Was it because the Navy did not want ships?

Admiral RICKOVER. Not ships. I am talking research and development.

Senator JACKSON. I think for the record it should be said that 2 years ago as a result of the work of this committee, Admiral Carney dropped one of his conventional submarines and added an atomic one. But there has been a lag, there is no doubt about it. There has been hesitation to take on something new. I think it unfortunate that just 2 years ago we were building 4 conventional submarines or 5.

Admiral RICKOVER. The fifth one of these conventional guided missile submarines was changed over to nuclear power. We are using a reactor for a 578 class and we are installing it in what started out as a conventional guided missile submarine at the Mare Island Naval Shipyard.

Senator JACKSON. The proposition was the Navy had asked for funds at a time when you had not commenced the trial runs for the *Nautilus*.

Admiral RICKOVER. Yes, sir.

Senator JACKSON. Subsequently, the trial runs took place but apparently someone failed, down in the Navy, to take cognizance of those results and so we had before the committee the fact that they were asking money for conventional submarines without having taken into consideration the results of the *Nautilus*. It was one of those unfortunate things. Admiral Carney was decent enough to admit it, but it was a lag that occurred and they did correct it to the extent of one.

Representative PRICE. I think the Navy has not asked for more.

Senator JACKSON. More conventional submarines?

Representative PRICE. That is right.

Admiral RICKOVER. You do have Admiral Burke over the barrel to this extent. Prices are going up 7 percent a year on everything. The Navy gets a certain amount of money for ship construction in accordance with the President's proposals, and the Bureau of the Budget. The nuclear-powered ships cost a lot, but he still has to meet today's problems and commitments.

I would strongly urge that for any development type ship there should be a separate budget. This would encourage the Navy to go ahead and try out new ships. As long as you attach costly development type ships to the one shipbuilding budget it poses an almost intolerable situation for the people responsible for running the Navy. It would not do any good to set up another budget but reduce the regular naval construction budget. That would not help. If something like a separate additional budget for the first of a development-type ship could be set up it would be a tremendous help in improving the Navy.

New type ships are very expensive, so if the Navy could be encouraged by having a separate budget for the first development ship of a type it would be a very tremendous thing. Because now Admiral Burke is spending for the nuclear-powered cruiser and for the nuclear submarines—and I imagine that is why there are only four submarines in fiscal 1958—he is spending quite a considerable portion of the shipbuilding funds on just a few ships, but he has many world commitments to meet, so what else can he do?

Representative PRICE. On your shipbuilding reactor program, are you just working on 1 type of reactor for each ship or do you have 1 or 2 or maybe more reactors that you are exploring for the various ships?

Admiral RICKOVER. For the submarines we are exploring different types, but for the surface ships, because of the large amount of development money involved, we are only working on two different types. That is for the aircraft carrier and the cruiser. Considering the many billions of dollars——

Representative PRICE. You mean 2 types for each ship or 1 type for the aircraft carrier and 1 type for the cruiser?

Admiral RICKOVER. It is immaterial whether it is for either one. We have a reactor a certain size.

Representative PRICE. They would fit in each ship?

Admiral RICKOVER. They would fit interchangeably. It would be wise from a national standpoint to be working on more than two types, considering the fact that we are going to be spending many millions of dollars on these ships.

Representative PRICE. Have you recommended we work on more than two types?

Admiral RICKOVER. I would like to recommend it. I would like to be encouraged by you to recommend it.

Representative DURHAM. That is the prototype land base you are speaking of?

Representative PRICE. If you think there is some question about the feasibility of it there might be a possibility of getting a more efficient reactor from one of them. I do not know why we should not explore it.

Admiral RICKOVER. You see, Mr. Price, we cannot ask for just any sum of money. We have to ask for something within reason. And I say, the Commission certainly has treated me very decently. But if I thought I could get more money, I would ask for more, because I know I can use it wisely.

Representative DURHAM. AEC furnishes all the money for prototypes for shore bases?

Admiral RICKOVER. Yes, sir; the AEC does that.

Representative DURHAM. Have you any new ones planned in the program?

Admiral RICKOVER. There will be one new one, but we have not asked for it yet. It has not gone far enough. It will be the frigate prototype. We expect to install it in the sphere at West Milton. We expect to ask for it in fiscal 1959.

Representative PRICE. Do you have in mind any particular type of reactor you would like to experiment with?

Admiral RICKOVER. Yes, sir; I would like to work on another type of reactor that would fit into a cruiser or an aircraft carrier. We are doing two different types now. I think it is important enough that we should do still another one.

Senator JACKSON. Mr. Chairman, I think it would be helpful, without going into it now, if we could get from the Admiral some indication of what additional funds he feels he needs. We requested it of him. It is not in the budget for fiscal 1958, under the request relating to reactors, research and development, and that whole area. If you could submit that to us at our request?

Admiral RICKOVER. I can give you a rough round figure. I could use $20 million. I could use in this fiscal year about $7 million or $8 million more. I could use a total of $20 million and get good use out of it.

Senator JACKSON. Just AEC funds?

Admiral RICKOVER. A combination of AEC and Navy funds. It would be roughly $10 million AEC and $10 million Navy. It is immaterial where the money comes from. I think you know we use some of it interchangeably. Your committee knows it and has approved of it.

Representative PRICE. How much do you need for this shipbuilding reactor program for one additional approach?

Admiral RICKOVER. It would take about $10 million.

Representative PRICE. About $10 million.

Admiral RICKOVER. About $10 million.

Representative VAN ZANDT. Have you the personnel?

Admiral RICKOVER. I can train additional personnel. That is a problem that comes up with any new program. If you have got to do something and you have an organization, you just go ahead and get more people and train them. No one doing a real job ever has any extra people.

Representative COLE. What are the two types you have now?

Admiral RICKOVER. We have two types which are good either for the aircraft carrier or the cruiser.

I will sketch it. You have in the center a part that is enriched uranium, and surrounding it is natural uranium. This is what we use on the PWR. In the PWR there are about 70 kilograms of U–235. The rest is natural uranium. The reason we have designed the core this way is because we are trying to use a minimum of enriched uranium in the large cores. We have to have enriched cores in the little reactors such as those for submarines, but for the larger ones we try to use as much natural uranium as possible, because to use enriched uranium entirely simply means running the natural uranium through a diffusion plant, and so burning up coal. There is not much sense to burning up a lot of coal, and then put it in a ship and use it for power, unless there is no other way to do it.

We are using the same principle of using as much natural uranium as possible, which can be used in one of the reactor cores which we are designing now, either in the aircraft carrier or the cruiser. We have designed it this way in order to have a minimum dependence on diffusion plants. We do not like to use too much enriched uranium because it is the same as burning up coal indirectly.

Representative COLE. Was it new?

Admiral RICKOVER. I do not know what it would be.

Representative COLE. I thought you had a concept.

Admiral RICKOVER. No, I would like to turn it over to the scientists working on it and have them come up with another type. I know I would like to design another one, but I do not yet know what it will be, sir.

Representative PRICE. I wonder if you could explain the different models so we know what we are looking at.

Admiral RICKOVER. Yes, sir. Let me first show you these charts. This is the control cubicle, the complete control for the propulsion plant of the submarine. This is where the operator controls the tur-

bines, and this is where he controls the reactor, and this is where he controls the electrical plant. This cubicle is very small. I think you are familiar with the large control stations you normally see around the various production plants. We have to get the control station very small. This shows you how small we can get it.

This chart shows the reactor which can be used either in the cruiser or in the aircraft carrier. This model of a man shows its actual size.

We have ordered the reactor pressure vessels both for the cruiser and the aircraft carrier. They have been ordered by competitive bidding. We have ordered the heat exchangers for both of those ships on competitive bidding, too.

This is a pretty good picture of what the aircraft carrier will look like. It has a 1,040-foot water line length, and almost 1,100-foot length flight desk. Her displacement will be about 86,000 tons.

Representative DURHAM. Could it get through the Panama Canal?

Admiral RICKOVER. No, sir. Nor can the other large carriers.

Representative VAN ZANDT. Is it possible to build a reactor into those ships with sufficient fuel to provide propulsion for the life of the ship, based on, say, 15 to 20 years.

Admiral RICKOVER. I would say this: with the type of operations we are doing now we sure should get about 5 years of operation.

Representative VAN ZANDT. Five years?

Admiral RICKOVER. Five today. But progress in reactor design is going so fast, sir. I think you could figure that ultimately you might get a reactor which will last the life of the ship. The goal we have now is to design a reactor which will last for a war. I think we have come pretty close to that. That is a great thing in itself because nuclear-powered ships will not need oil bases and oil storage tanks and oil tankers. Furthermore, you could store all the fuel you need for a nuclear navy in a few buildings. The fuel is not radioactive, and if you do not use it for the Navy you can always convert it to other uses.

This is the guided-missile cruiser. It is 690 feet long with a beam of 70 feet. This cruiser will be built at Quincy, Mass. It will displace about 14,000 tons.

This picture shows a preliminary design of a nuclear powered destroyer. We already have the nuclear propulsion plant in an early stage of design. The Knolls Atomic Power Laboratory is designing the reactor.

To show some of the models I have brought, this is a cross section of the core in the 578 class submarine. This is one of the fuel elements, and these crosses are the control rods.

This model is the machinery space of the 578 class, and this is the reactor plant.

We have two different types of reactor compartments for these plants. We have one where we use a tunnel type shield, that is, we spread the machinery out, and we use the B–29 tunnel concept of just shielding the passageway where the people walk through. The other type uses a regular shield deck like in the *Nautilus* where everything is under the shield. We are trying out both of these. We are building two ships of each type, and are going to try them out in service and see which is the better.

This is the *Albacore* hull type submarine. This is a cutaway of the pressure vessel and the core. The core is down here, and this is the

control-drive mechanism. You can get an idea of what the pressure vessel head looks like.

This is a model of the 578 class submarine.

This is another model of it.

This is a very interesting reactor.

This is the reactor which will go into the large radar picket submarine. It is a different type than the others. The others all use plates for fuel elements.

I have here a sample of a control-drive mechanism for the aircraft-carrier core. This one will be used at the carrier plant prototype at Arco. As you know, that prototype has two reactor cores.

Here is a sample of the control drive mechanism for the radar picket submarine. It is being designed by the United Shoe Machinery Corp., of Beverly, Mass.

Representative DURHAM. Is the shoeman in this business too?

Admiral RICKOVER. The United Shoe Machinery Corp. is pretty good in developing mechanisms. You see in the shoe business they have to use a lot of very complicated machinery. They are experienced in developing mechanisms. This gives you some idea of how we are spreading our development out.

Senator JACKSON. The Russians will have a terrible time trying to figure out what the American corporations are doing if they just read the stock lists and try to make a decision.

Admiral RICKOVER. That is right. We have companies such as Borg-Warner, Bendix, and Aerojet making controls. We have all kinds of companies in our business.

This model shows the pressurized water reactor. You will have to come closer to see it.

The scale of this PWR model is, I think, one-eighth. This is the core. This is the core loading and unloading mechanism.

I do not know if we brought one of the 600-pound bolts here or not.

Representative DURHAM. No.

Admiral RICKOVER. These bolts are 6 feet high and weigh 600 pounds, and secure the head to the pressure vessel. There are 43 of them. You can see that they are large items.

I wanted to talk a little bit about declassification before it is too late, because Dr. Libby has been involved in this. There has been a lot of criticism of the Commission for not putting out more information. So recently we declassified all naval reactor technology, but not the designs.

I would like to make a distinction between technology and design. I must make this clear so you do not misunderstand me. The experimental information which has been developed in the naval program is now unclassified and is available to all of our industry. But the actual details of the designs are confidential. That is, we do not give away design details.

The PWR is completely declassified and all the design details as well as the technology is now available to the public. We just started putting out all of the PWR reports on an unclassified basis. In naval reactors program all of the technology, all of the scientific and engineering information that anyone in this country needs to know to build a water-cooled reactor can be obtained. But we do not give away actual dimensions and design details except to those who need to know them.

There were two good reasons for doing it. One, as I see it, the Government is directly and indirectly subsidizing everybody anyway, so we might as well give them the information.

The other thing is it is getting too darn hard to operate with so many people coming into the laboratories and getting the information personally. We either had to spend much of our time and the time of the people in the laboratories handing out the information on a personal basis, or else do this through declassification. We decided it was better to take a little bit of a chance and so be able to get ahead with our own work. What we have done is, I think, rather significant. It will take some of the curse off the Commission and they will not be accused so much of not handing out information.

We have done another thing in the naval reactors program to make information public. We have put out a series of manuals on our program over the past few years.

We have published five manuals so far: The Liquid Metals Handbook, Metallurgy of Zirconium, the Metal Beryllium, Reactor Computer Codes, and the Reactor Shielding Design Manual. I have copies of these books here on the table. Another manual, Corrosion Handbook for Water-Cooled Reactors, should be published in about 2 months. There are five more on various technical subjects being written. They will all be published within about a year and a half. All of these manuals are completely unclassified. They are all real working books for people who have to do reactor design work. A man can use the shielding handbook, for example, and design a shield.

Representative HOLIFIELD. What is your evaluation of the philosophy behind making, let us say, all the shielding information or all the metal information like zirconium available? That immediately, of course, becomes available throughout the world. Do you think that gives us a disadvantage with our enemies?

Admiral RICKOVER. Certainly it does, sir. But this is the problem we are facing all the time: You get more of an advantage than you get a disadvantage. You get much more of an advantage because you get the information out to your own people. There is no use in subsidizing a lot of people to do work on zirconium in the United States and hinder them by not giving them the information which is available. But another serious thing——

Representative HOLIFIELD. In other words, the know-how, you are training them for a wider basis of participation.

Admiral RICKOVER. The information in the zirconium book does not tell you how to design a core. You have to get much more information to be able to do that. But it does have the complete story on how to make and use zirconium. I am not so sure other people are not just as smart as we are, anyway.

I think sometimes when you lock yourself up in a room and put the restricted data tag on it, I think perhaps you are kidding yourself more than you are other people. You can very soon get yourself in the position of thinking that you know it all, when you really do not.

These handbooks are put out commercially, by the way, and the publishing companies want to print them. By having these books available you get the people in the universities and in other places starting to think about the problem and making improvements. I do not think we could have gotten lower prices on zirconium if we had not made this information widespread.

Mind you, these books contain technology. We are not putting out actual design information on the dimensions of the shield for any of our ships. We do this for the PWR. That shield is concrete anyway.

Representative DURHAM. Was that not the first book published entirely on zirconium?

Admiral RICKOVER. There have been many papers published on zirconium, but this book is now the standard for zirconium all over the world, as far as I know. It certainly has all of the latest information in it.

It has another advantage. It was written by the people who are actually working with zirconium. Normally, text books are about 10 years out of date by the time they are published. But when it is done by the people who are actually working on it you have something right up to date.

Representative HOLIFIELD. In other words, the diffusion of this knowledge, you figure, among a wider base of potential engineers and scientists and so forth will give us the capacity for rapid advancement which you could get no other way.

Admiral RICKOVER. I will call on Dr. Libby to remind him of that famous day quite a few years ago when I appeared before his committee—he was at that time the chairman of the senior reviewer's committee—urging him to back us in putting out a Liquid Metals Handbook. That was about 1948, and it was the first time there had been any declassification in reactors. As a result of the Liquid Metals Handbook we got people in the universities and in other places to start working in this field.

You will find that today these are the standard books in the United States on this subject. There are no others. There are not any others with detailed scientific and engineering information in this field. So you have to make up your mind 1 of 2 ways. You are either going to keep the information locked up in Government or give it to industry and to the schools and so make it available to many people.

Sure you are giving information away. Is that not one of the strengths of a democracy, that we assume we can live in a democratic way and still stay alive? It does not mean that we must give away all the details of everything, but it does mean we must give away enough so that our own people can be aware of our problems and help us. You cannot give without taking chances.

Representative HOLIFIELD. It is the only way you can really widen the base in this shortage we have?

Admiral RICKOVER. I am not talking now, believe we, from a theoretical standpoint. We declassified information because we found out that our work was being hampered.

Representative VAN ZANDT. Admiral, are these books becoming part of the atomic library that the AEC is planning throughout the Nation?

Mr. RODDIS. Yes, sir.

Admiral RICKOVER. There are quite a few more coming out.

As I have said, six more are coming out in the near future. There is one every half year or so.

Representative DURHAM. Have you declassified the separation of hafnium from zirconium?

Admiral RICKOVER. Yes, sir.

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Representative DURHAM. When did you do that?

Admiral RICKOVER. I think in the last 2 or 3 months. We will include this information in the Hafnium Handbook which is now being prepared. We found out the Russians know about hafnium anyway.

One other thing I believe I should tell you is how we run our projects. We operate the Naval reactors program in somewhat of a different way than other programs are operated.

There are two theories for running reactor programs. One is to assign it to a contractor and give him the money and let him run the job all by himself. The other way is to retain control at a headquarters organization.

When you have to design and build a reactor for a ship you cannot turn it over to somebody else because it has to be integrated right into the ship. For instance, a submarine has to have neutral buoyancy. You cannot leave it up to a contractor to start designing the reactor, and a year after the ship is started you suddenly find out that the reactor weighs too much. The ship will sink.

So our philosophy has been from the beginning, and we have used it on the PWR also, that the Naval Reactors Branch approves the details of the design. We keep in constant touch with what the reactor designers, the machinery designers, the shipbuilders, and the construction contractors are doing.

We have in my organization at headquarters about 90 officers and civilians. They constitute the headquarters engineering and administrative staff.

These people work both for the Atomic Energy Commission and the Navy interchangeably. There are officers and there are civilians, and I think you all know that I assign people to positions on the basis of ability and not rank, or whether he is a civilian or an officer. The best qualified man gets the job.

We operated this way for a long time, and it is now accepted. In my opinion it is the only way you can run any kind of technical organization; put the best people in the most important jobs.

Senator JACKSON. Would you explain the two hats I think you wear at some point?

Admiral RICKOVER. Yes, sir. My primary duty is on assignment to the Atomic Energy Commission. I am Chief of the Naval Reactors Branch of the Atomic Energy Commission. So I act for them with the AEC laboratories and other activities. I have an additional duty as Assistant Chief of the Bureau of Ships for Nuclear Propulsion. That means that anything that has to do with the nuclear-populsion plant for the first vessel of a type comes under my cognizance. Of course, I am responsible to the Director of Reactor Development in the Atomic Energy Commission and to the Chief of the Bureau of Ships in the Navy Department.

Senator JACKSON. Is this two-hat system working?

Admiral RICKOVER. Yes, sir. I would advise anyone who has a large-scale development job to do to adopt 2 hats or 3, whatever number is necessary. It is a new experiment in development administration. We have never had anything quite like this. We have always had liaison among bureaus and between one Government agency and another. But here there is one group of people working for both a civilian agency and a military agency. It is sometimes a little diffi-

cult, but it works, and it works particularly because the AEC people have sure stood for a lot from us—I don't know why, but they do—and they deserve a great deal of credit for their forbearance and their help. In my opinion, this type of Government operation is absolutely essential in the future for any large-scale development operation. If you do not have it this way you get fouled up with lots of redtape.

Representative VAN ZANDT. Is there any effort afoot to dissolve this unique organization you have?

Admiral RICKOVER. I do not know. I would imagine there are people in some places that are not too happy with it, but I certainly hope, whether it is me who is involved, or someone else, that this organization not only is not dissolved, but I would strongly urge that people in Congress should eye this method as a new form of Government research and development administration. I think it is absolutely essential that the military no longer attempt to fight wars all by themselves, or do large-scale research and development all by themselves.

My organization is really more than a two-hat one, sir, because it includes more than the AEC and the Navy. Actually there is a third hat—industry. I think some of you know how closely we work with industry. We have gotten a real integration of industry, the Navy, and the AEC on this job. There is no other way we can do it.

Representative PRICE. We are getting close to that point at least. Could you explain your Branch? The Naval Branch of the AEC is set up to carry on the Shippingport project?

Admiral RICKOVER. Yes, sir. The PWR Shippingport project was assigned to me by the Commission because of the previous experience that my group had had with pressurized-water reactors. The Westinghouse Co.'s Bettis plant was assigned to do the necessary development work. The development work is now almost finished for the first core. The Duquesne Light Co. was selected from among nine contenders to be the operator of the entire plant because they made the best financial offer to the Commission. But my organization is responsible to the Commission for the design, the construction, and the operation, and we spend a great deal of time on it.

The Bettis plant submits the nuclear-plant designs to us and we analyze them and reach joint agreement. In many cases the Duquesne Light Co. is also involved in nuclear problems, because they are going to operate the plant. We are able in this way to reach quick decisions between the Government, Westinghouse, and Duquesne.

We are able to operate this way because there is a single, assigned responsibility. Otherwise, we would all be writing letters from now to doomsday, between the Commission and somebody else, to get permission to do anything. We are able to do our work with few letters and no fuss. There has never been a single letter written between the Commission and the Duquesne Light Co. since the contract was signed with them. It has never been necessary, because all of the dealings have been done orally between myself and their manager or Mr. Philip Fleger, their chairman of the board.

Representative PRICE. You mentioned a minute ago you had about 90 people in your headquarters organization. Is that strictly for the ship-reactor program?

Admiral RICKOVER. No, sir; that includes people who work on the Shippingport reactor. But, besides these people, we use somewhere

between 150 and 200 people in the Bureau of Ships to work with us not only on the naval program, but also to help on the Shippingport project. It makes no difference what Government people do the work, because the money all comes from the same source. The Navy is glad to help, because we are not only helping the Commission and the country, but we are also learning a great deal for the naval program by doing so.

We try as far as possible not to duplicate facilities between the Navy and the AEC. For example, when we buy nuclear cores on competitive bidding for the Navy, for which the Navy pays, we do it through the AEC. If we did not do it through the AEC, we would have to set up a separate organization to account for the fissionable material, and to prepare the specifications, to inspect the cores, and to take care of other items.

So far, we have been permitted to use the Atomic Energy Commission facilities for this purpose. I strongly urge that, wherever we can, regardless if the core is for a naval reactor, as long as the AEC has the people and facilities for doing so we should use them, and not set up additional, duplicate, Government organizations. It is not only wasteful of manpower and money, but every additional organization you set up saps your strength and does not give you time to do your technical work. You get completely bogged down with administration and redtape.

Representative PRICE. Have you moved this Shippingport organization over to some other project intact, or what will you do with that?

Admiral RICKOVER. We are working on a new core design for the PWR reactor. The present core is designed for 60,000 kilowatts of power. The Commission authorized us about a half year ago to work on a new core which will be of an improved design. The new core is being designed to generate 100,000 kilowatts of power and to produce this power more cheaply than the first core. We have already started the new core design for the PWR reactor.

Representative PRICE. How close do you come to keeping any sort of schedule on the Shippingport project?

Admiral RICKOVER. We have not come close to keeping on schedule.

(There was discussion off the record.)

Representative PRICE. I saw where you got considerable publicity on a speech you made recently about the engineering and technical problems encountered in the atomic-power program. In view of your experience with PWR and Shippingport and other facilities, do you think we have a realistic schedule now on our current atomic power development program?

Admiral RICKOVER. From my experience so far, I would say that all reactors are going to cost considerably more and take considerably more time to design and construct than was originally anticipated. I am, of course, talking from my own experience, but certainly we are pushing our programs hard and still running into many delays, so I would think other people are going to experience the same thing. As you know, the costs at Shippingport have gone up.

Representative HOLIFIELD. How much have they gone up?

Admiral RICKOVER. Congress originally authorized the Shippingport project for a total of $100 million. We estimated then it would cost $85 million. The latest cost estimate as of today is about $42 million for research and development and $55 million for construction

of the nuclear portion of the plant. Of this $55 million, $5 million was given to the Government by the Duquesne Light Co. as part of the contract we made with them when they were selected. So the Government cost is $50 million for construction plus $42 million for research and development, which makes a total of about $92 million. That will be the cost provided we can finish it in a reasonable time. If the time is stretched out, the cost will go up.

(Discussion off the record.)

Admiral RICKOVER. The costs of all reactors are going up, sir. I would estimate from what I have seen you can expect probably at least a 50 percent increase in all of the large reactor projects. I am talking from my own experience. This is what my experience indicates.

(Discussion off the record.)

Representative PRICE. Admiral, going back to your experience at Shippingport now, do you think your trained force, experienced people, with the experiences they obtain and develop at Shippingport and other jobs in your program, could take on the job of building a large-sized, gas-cooled reactor to supplement the present power program?

Admiral RICKOVER. Mr. Price, you know I am not responsible for civilian reactors.

Representative PRICE. I know you are not. I am just asking, do you think your people, at least from Shippingport experience, would be interested in such a project and kind of like to undertake such a project?

Admiral RICKOVER. If it were assigned to us we would take it. That is up to the Commission.

Representative PRICE. Would you like to do it?

Admiral RICKOVER. Sure, I would like to do it because most of the people in my program are not in it for the naval program alone. They are interested in helping to bring atomic power to our country, because they believe atomic power is necessary for our future welfare. The Navy is helping to bring atomic power to our country because whatever we develop or learn in the naval program is of use in civilian reactors.

Representative PRICE. Do you think your group is in pretty good shape to take on an assignment like that?

Admiral RICKOVER. No, sir, we are not, but we could put ourselves in shape.

Representative VAN ZANDT. Projecting our thinking into the future, Admiral, when your reactors are standardized as far as ship propulsion is concerned, would it then be necessary for this unique organization you head to continue?

Admiral RICKOVER. For quite some time, yes, sir; because the whole reactor game hangs on a much more slender thread than most people are aware. There are a lot of things that can go wrong and it requires eternal vigilance. All we have to have is one good accident in the United States and it might set the whole game back for a generation. We do not want that to happen.

It requires a high order of ability and intelligence among the engineers and a high order of watchfulness to insure that nothing goes wrong.

Representative PRICE. Let us get back for a minute to the point I raised in regard to your recent speech about a realistic schedule in our power program. Do you think the target dates for around 1960 and 1962 are realistic?

Admiral RICKOVER. For what, sir?

Representative PRICE. For a large-scale operation of power reactors.

Admiral RICKOVER. To have a considerable number of power reactors in the United States?

Representative PRICE. Yes.

Admiral RICKOVER. No, sir.

Representative PRICE. What do you think would be a realistic target date?

Admiral RICKOVER. You are really getting me out of my field and I think you have people here far more expert on that than I am.

Representative PRICE. I am asking your personal opinion. You have had quite a bit of experience in the reactor building program and are not entirely unfamiliar with the power program.

Admiral RICKOVER. I think some of the people working on the program are not entirely realistic, they are not facing up to the facts of life. I do not think they have had enough practical experience. I do not think they worry enough.

You see, when we design reactors we have to think of putting them into a ship, and I have one design criteria. I always ask myself, would I want my son to go in the ship? If I can answer that question affirmatively, I say it is all right.

Representative PRICE. When you say they are not considering all problems, what would you mean by that?

Admiral RICKOVER. For instance, some of these reactor designs, as I see them, do not take into account some of the things that might go wrong, so they do not put into the design enough features, in my opinion, which would take care of them.

Representative PRICE. In other words, you do not feel the reactor is a proven thing until you know what it would do in event of an accident.

Admiral RICKOVER. That is why we build prototypes and try them out.

Representative PRICE. What do you think—I am just trying to think of an example of what you are talking about there. Would you say EBWR at Argonne, for instance, is a proven thing until you have something go wrong there?

Admiral RICKOVER. No. As far as I am concerned, all EBWR has so far proved is that if you get enough uranium together you have a critical mass. I think Argonne has done a fine job in designing and getting the EBWR in operation so fast. They are learning from it a great deal about control and operation of boiling water reactors. But until they fully try it out and, deliberately perhaps, have a ruptured fuel element go into the system and see what happens, I do not think they have finally proven the reactor system.

Representative PRICE. They have never done it?

Admiral RICKOVER. I think probably they will do it.

Representative PRICE. They have not done it yet?

Admiral RICKOVER. As far as I know, not.

Representative PRICE. Of course not with the new reactor, but with any similar type reactor have they done it?

Admiral RICKOVER. In my opinion, I see no point in conducting experiments of that kind unless you finally go to the bitter end and see what happens if you do have a burst fuel element. Only then will you know whether you will be able to operate the plant or not.

Representative DURHAM. Did they not test the one prior to Argonne?

Admiral RICKOVER. As far as I know they are planning to do this, but as far as I know—probably Commander Roddis knows better than I do.

Representative DURHAM. Was not the original borax tested, Doctor, originally?

Mr. RODDIS. There have been three experiments of boiling water reactors conducted: Borax 1, 2, and 3. One of them, borax 1, carried to destruction. Borax 2, during its operation and later borax 3, during its operation, have operated with aluminum fuel elements, which have received pittings, according to previous information. The type fuel element being used in the EBWR is a different type of fuel element which is much more susceptible to corrosion than the borax reactors.

Admiral RICKOVER. What I was saying was this: Until there is a burst fuel element and it gets into the system and you see whether you can operate the plant the experiment is not finished. That, to me, is the most important part of the experimental program on a reactor of that type. I am sure they will do it.

Representative HOLIFIELD. Let me try to follow you on this. Have you done that in the prototype of the PWR reactor?

Admiral RICKOVER. You see the PWR reactor has heat exchangers so that the water which goes through the reactor is kept separate from the steam system. But in a boiling water reactor the steam goes directly from the reactor to the turbine. We deliberately burst a fuel element in our submarine prototype plant at Arco and because of the heat exchangers in the system we were able to keep on operating.

Representative PRICE. That is what we are trying to find out, what you meant by that.

Admiral RICKOVER. These are the things you have to take into account in a naval plant. We have to postulate that these things will happen. So that even with a burst fuel element at Arco we were able to live with it. We have also had more than 100 gallons leakage of water per hour but we found we can live with it.

A lot of complication in our designs is due to the fact that we go to great expense and trouble to visualize these sorts of situations and in designing for them. This is what makes our plants complicated and expensive.

Representative PRICE. What sort of management controls do you use?

Admiral RICKOVER. I receive once a week a series of critical items lists from each of our projects. These are the items that are in design trouble, or need help, or where there is delay or there is something wrong. We give immediate attention to these problems.

Representative VAN ZANDT. You write no letters?

Admiral RICKOVER. We do write letters especially on technical matters, but a great deal of our work, particularly on expediting development and manufacture, is done by telephone. We do not wait, We get after this kind of stuff right away.

We also receive technical progress reports regularly from our contractors, and we comment on them. If you will look at these [indicating] you will see the type of reports we get on each project. We try to get the reports in 10 days after the end of the month or whatever the reporting period is, and we comment on it and tell the contractors and laboratories what we do not agree with. We do a lot of this sort of work all the way through each project.

Representative PRICE. How many people are there in the naval program?

Admiral RICKOVER. We have at Bettis about 1,300 scientists and engineers These take care of the PWR project also. At the Knolls Atomic Power Laboratory, about 500; at combustion engineering, about 200; which makes a total of 2,000. At the laboratories and factories of our subcontractors there are probably an additional 1,000 scientists and engineers. Therefore, there are about 3,000 scientists and engineers working in the naval program plus the PWR.

On a project like the PWR it takes about 250 scientists and engineers, plus another 750 people, 5 years, roughly, to do the development work. That is pretty much the number of people and the time required for the research and development of any of these large projects.

These are fairly well trained people, not people you hire right now or pick off the street. A good many of them have come from the parent organization and have not been newly hired from outside.

Representative HOLIFIELD. In other words, some group that starts to build one of these large-size reactors without this organization——

Admiral RICKOVER. They will take several years to really learn.

Representative HOLIFIELD. Several years to perfect their organization to the point where you have it now, is that right?

Admiral RICKOVER. Yes, sir. It took us quite a few years to do it. My organization has been in the process of being formed for quite a few years. We are constantly training people. Every engineer or scientist I hire goes through a special selection system, the officers as well as the civilians, and we give each one of them special courses of training in the reactor field. Every engineer in my office has been given specialized education.

Representative PRICE. You give them training on the projects?

Admiral RICKOVER. Training at schools too.

Representative PRICE. What type of schools?

Admiral RICKOVER. The Oak Ridge School of Reactor Technology, Massachusetts Institute of Technology. We have schools at Bettis also. The school there lasts about 6 months. Every one of our engineers, officer or civilian, must attend one of these schools.

The young officers we get must agree to stay for 4 years before they can come into my organization, and many of them stay on as civilian engineers after their naval time is up. They stay with us because the work is interesting and they are able to do as much as they are capable of—to fulfill themselves. You have got to train people if you want to keep them.

Representative DURHAM. You have regular Navy personnel working for you, do you not?

Admiral RICKOVER. Yes, sir; I have Naval Reserve, regular Navy, and civilians.

Representative DURHAM. How about the pay schedule? Ordinary civilians, say as a civilian engineers, do they complain about the difference in pay?

Admiral RICKOVER. No, they do not. The officers are really discriminated against in this situation. We have fairly young civilians working right alongside officers with a good many years of service, and the civilians get more pay.

I hope that the Cordiner report, or some similar measure is placed into effect to take care of the outstanding and motivated officers in my organization. Although our people are not working entirely for money, nevertheless nearly everyone in my office could get a job at a much higher salary. We have a very low level of departures.

Representative DURHAM. Have many left you?

Admiral RICKOVER. No.

Representative DURHAM. Naval personnel, I am talking about.

Admiral RICKOVER. We have had more naval personnel leave than civilians, but our rate of attrition is not high.

Representative VAN ZANDT. Is it a change of assignment or do they resign?

Admiral RICKOVER. The officers who have left, generally get out of the Navy. They say they are not making enough money to support their families properly, and there are many opportunities in industry at much higher pay for people who are as qualified in this field as they are.

But most of them, not all, who have left have not been the most outstanding. Commander Roddis, however, was one of our outstanding people.

Mr. RODDIS. I did not leave for money though.

Admiral RICKOVER. No. But some who have left—we have not cared very much whether they left or not. In general, our good officers stay around, and I think you can get people to become dedicated to a job where they feel they are doing something constructive and worthwhile—they learn that money is not everything in life. And, of course, it is not. There is also personal fulfillment when you are doing the kind of job you like to do, and that is really the important thing.

Representative PRICE. What kind of action do you get out of AEC area offices on contract expediting?

Admiral RICKOVER. The AEC area offices do a good job for us. The whole AEC does a good job for us. It is a very fine organization. As I said before, without the AEC we would not now be on the way to a nuclear-powered Navy.

Representative PRICE. In many of your cases, do the area offices handle the contracts?

Admiral RICKOVER. Yes, sir. I do not know what the figure is. Up to a certain amount they can be handled locally in the local AEC offices, and anything over about $2 million has to come into Washington.

Mr. RODDIS. It varies with different offices. Mr. Flaherty at Argonne has authority to make contracts for $5 million.

Admiral RICKOVER. I would like again to state Admiral Holloway—our Chief of Naval Personnel—has done an outstanding job in taking care of our needs. He has helped us tremendously.

Representative VAN ZANDT. Some years ago we were concerned about the possible thievery, we will say, of trained personnel from your organization when authority was granted to establish, we will say, the shipbuilding capabilities in this atomic field. Has that actually taken place?

Admiral RICKOVER. You mean, has there been any trouble with pirating of people trained in the nuclear field in the shipbuilding organizations?

Representative VAN ZANDT. That is right.

Admiral RICKOVER. There has not been much, sir. You see, whenever a new shipbuilder gets into this game we know it ahead of time and we train his people; we arrange for his people to go to school. We also send people from my organization to deliver lectures and to advise them on training. We have set up, not only for shipbuilders but for every industrial outfit that comes into our game, a system of training.

Let us take metals and controls, as an example. We sent people there to deliver lectures, and we arranged for their people to go to schools. This is part of the regular course of training.

It so happens that Captain Dunford is responsible for that phase of our work in my office. We make sure that all of the industrial companies that work for us are trained. We cannot just let them do this by themselves because they do not know how to go at it. And that applies to the shipbuilding companies, too.

Representative VAN ZANDT. Is Ingalls down in the gulf developing capabilities to build submarines—atomic submarines?

Admiral RICKOVER. Yes, sir.

Representative VAN ZANDT. How long is it going to take them to assemble trained personnel?

Admiral RICKOVER. They started 2 years ago. Two years ago, when it was decided they would enter the submarine field, we started training their people. Now they have a number of people who are qualified. But it will take much more training. It takes several years. The Newport News Shipbuilding & Dry Dock Co. and the Bethlehem Steel Co.'s shipbuilding division at Quincy, Mass., have been training their people for several years in the nuclear field. We have helped them. They are still giving special training to their people. It takes several years to train a shipbuilding organization to become reasonably competent to build nuclear-powered ships. They must change some of their previous methods. It takes higher skilled people than you usually have in the shipbuilding industry.

For a company to get ahead in this game at the present time they must assign their best people and the man in charge must be of top-management caliber. The companies have done this. They needed some urging, of course, but once their managements finally saw the nature of the problem, they did what was necessary. We have had trouble, but we have been able to obtain cooperation. Perhaps you were referring to the Committee on Education that you and Mr. Price were on last year.

I said at the time I thought there were too many people just crying and wringing their hands and waiting for somebody to come along

and help them. In many cases they themselves can do much. Anyone responsible for a reactor project must take on the problem of seeing that his contractors and subcontractors hire the right sort of people and then trains them. Unless he does this he is in for trouble.

Representative VAN ZANDT. Then all of this excitement kicked up here a year or so ago about raiding your organization actually did not materialize, did it?

Admiral RICKOVER. No. No one is raiding my organization. Any one in my organization who wants to leave, I would just as soon have him out of it.

Representative PRICE. Are there any questions?

Thank you very much, Admiral, for a very fine presentation.

Representative VAN ZANDT. It was well done.

Senator JACKSON. I think he is to be commended always. We get forthright answers and he has done a good job.

Representative PRICE. The committee has always had fine relations with Admiral Rickover.

Admiral RICKOVER. You know how I enjoy coming up here. I know that you are all my friends and I sincerely thank you. I know you will do anything you can to help me in this program.

Representative PRICE. Thank you very much for your testimony this afternoon. It was very interesting and helpful.

(Whereupon, at 4:05 p. m., the hearing was concluded.)

PROGRESS REPORT ON NAVAL REACTOR PROGRAM AND SHIPPINGPORT PROJECT

FRIDAY, APRIL 12, 1957

SUBCOMMITTEE ON RESEARCH AND DEVELOPMENT,
JOINT COMMITTEE ON ATOMIC ENERGY,
CONGRESS OF THE UNITED STATES,
Washington, D. C.

The Subcommittee on Research and Development met, pursuant to call, at 10:30 a. m., in the conference room No. 1, Westinghouse Bettis plant, Pittsburgh, Pa. Hon. Melvin Price (chairman of the subcommittee) presiding.

Present were: Representatives Carl T. Durham (chairman of the full committee), Chet Holifield, and Melvin Price.

Staff members present: James T. Ramey, executive director, and George E. Brown, Jr.

Representatives of the Atomic Energy Commission: Kenneth E. Fields, General Manager; W. Kenneth Davis, Director, Division of Reactor Development; Rear Adm. H. G. Rickover, Chief, Naval Reactors Branch, and Commander V. A. Lascara, Naval Reactors Branch, John M. Bodley, special assistant to Commissioners Libby and Vance; Bryan F. LaPlante, congressional liaison officer; L. D. Geiger, Manager, Pittsburgh Area Office and Comdr. R. V. Laney, assistant to Pittsburgh area Manager (reactors).

Representatives of Westinghouse Electric Corp.; Charles Weaver, vice president in charge of atomic energy; John Simpson, manager, Bettis plant; Dr. Sidney Krasik, manager, central physics department; Dr. Benjamin Lustman, manager of metallurgy department; Mr. Alexander Squire, manager, submarine fleet reactor; and Dr. Walter Esselman, manager, advanced development group.

Representative PRICE. The meeting will come to order.

The Research and Development Subcommittee of the Joint Committee on Atomic Energy is here at the Bettis plant today in connection with its continuing studies in the atomic energy program. The joint committee is empowered to hold hearings at such times and places as it chooses and this meeting today is in keeping with the committee's tradition of visiting key installations as frequently as possible. First of all, I would like to commend the Government and private employees of Bettis. Your achievements in developing the *Nautilus* is of worldwide fame and I am sure my colleagues on the committee share my confidence that your work ahead will bring forth equally successful projects. I understand that Admiral Rickover will introduce this morning's speakers.

Will you proceed, Admiral Rickover?

STATEMENT OF ADM. H. G. RICKOVER, CHIEF, NAVAL REACTORS BRANCH, ATOMIC ENERGY COMMISSION

Admiral RICKOVER. First I would like to express for the Commission and for Bettis our appreciation of the opportunity to have you people here. We appreciate it a great deal and I am sure that by getting a firsthand look at some of the things that are going on here you will have a better understanding of what it takes to build a reactor plant.

Representative PRICE. Before you proceed, I would like to call to the attention of the gentlemen who are present here that while this is a subcommittee group here this morning, we are honored with the presence of the chairman of the full committee, Mr. Durham.

Admiral RICKOVER. It is a coincidence, but yesterday the *Nautilus* went to sea with her new core. Her core was successfully installed and she is at sea again. We have both the *Nautilus* and the *Sea Wolf* at sea. The *Sea Wolf* is at sea for about a month. She left early this week. However, the *Nautilus* refueling job is completed and the new core will give her significantly greater cruising radius. As you know, this new core was also designed by the Bettis Laboratory.

Since this meeting is intended to show what the Westinghouse Co. has done with the Bettis Laboratory, I will stop and introduce Mr. Simpson who is the general manager here. I think I should also introduce Mr. Weaver who heads up the nuclear work for Westinghouse and who was the first manager here. Mr. Simpson will take over.

Representative PRICE. Mr. Simpson, before you start I would like the record to show also that the General Manager of the Atomic Energy Commission, Mr. Fields, and the Director of the Reactor Division, Dr. Davis, are also present at this meeting.

STATEMENT OF JOHN SIMPSON, MANAGER, BETTIS PLANT, WESTINGHOUSE ELECTRIC CORP.

Mr. SIMPSON. Mr. Chairman and gentlemen, my purpose today is to try to tell you a little of what we at Bettis do; how we go about the work of the research and development and design of reactor powerplants.

As you know, Bettis was started about 8 years ago in order to do the work necessary to build the prototype of the *Nautilus*. We are very proud of the fact that the Bettis plant was started by Westinghouse taking largely people from other Westinghouse locations in an attempt to start the laboratory without taking people from other existing atomic-energy installations; that is to create a new factor in the atomic-energy field and not merely transfer existing technical manpower. We were quite successful in that and even today the average service with Westinghouse of the 400 supervisors at Bettis is more than 8 years. In the early days approximately 80 percent of all the supervisors, both technical and administrative, came from other Westinghouse locations.

At Bettis we do the engineering job on reactor powerplants, but in addition to that we do the necessary research and development that is essential for the engineering of those reactors. The reactors that we

have been working on in conjunction with the Naval Reactors Branch and the Pittsburgh area office of the Atomic Energy Commission for the latest submarines and the surface vessels have all been pressurized water reactors, but they are far different from the reactor that powered the *Nautilus*. There has been and there still is much research and development needed within the scope of the pressurized water reactor. It is a big development job.

As an illustration of the development required in the building of a reactor I would like to use the reactor core itself. In the reactor core we bring to focus physics, metallurgy, and straight engineering in the mechanical design sense of mechanical and thermal design. There is a big interrelation between the physics and metallurgy in the reactor design which requires an unusually close cooperation—a step-by-step development process—either one of which being adverse sufficiently can eliminate the material from consideration. So it is a typical problem to keep the two in balance.

Along this line it is relatively simple to determine, for example, that a new material appears to have great promise in a reactor; uranium-niobium, for example, or uranium oxide. In a few days a few metallurgists and physicists together can come up with the feasibility of such a material, but then there is an order of magnitude of tens to hundreds of times more work before you get to the point where you can actually use that material in a reactor. Uranium oxide, because it is an oxide, does not—it cannot further oxidize and it would be noncorrosive and inert in water. You can know in general what its physics properties are, but in order to really use it, many months and even years of development are required in the physics to understand how it is used.

In physics our reactor program has been limited in the past and still is to some extent by the lack of knowledge of the basic physics concepts. For example, until recently, there was difficulty in knowing exactly what the yield from fission was in the way of xenon. While this is not very important if you are just designing reactors in general, when you are getting down to the brass tacks of a particular design that must work, that and other similar constants, to a high degree of accuracy, become quite important.

The next area in which we must do a lot of work is taking the various assemblies of uranium of various enrichments and various geometrical configurations in determining the basic reactor. Having gotten through that, which usually requires a critical experiment which is an expensive and time-consuming thing, and which takes a great deal of technical manpower, we design the reactor.

Then in the design we must know other things than the basic parameters of the reactor. We must know exactly what is the distribution of neutrons in the reactor because that determines how the heat is produced and you must cool it properly in relation to the way the heat is produced, or you produce a hotspot and this may cause the reactor to melt down. You must know to a relatively high degree of precision the distribution of the flux.

Today's technology does not permit calculation on analytical techniques. This must be determined by experiment. We must determine how many control rods to use. We must determine whether or not the reactor will, in fact, be critical even with some of the rods not

all the way in, to be sure that it is safe. These things can be determined from a critical experiment run in a laboratory. A certain amount of the dynamic action of a reactor can also be determined by laboratory experiments.

Then you get into the more difficult things in which we must have a good basic theory in order to extrapolate, and the most important of these is the lifetime behavior. As you know, a power reactor must last for many thousands of hours. Uranium is burned and plutonium is formed. These are the fissionable materials and, therefore, the net reaction varies with time. You must determine and predict in advance what the control situation will be and what the flux distribution will be even after many thousands of hours of operation. This we cannot do by experiment in a laboratory because, in fact, it depends upon running the experiment at power for long periods of time. This information is verified from data we get from such reactors as those at Idaho, from the naval reactor facility, from the *Nautilus*, and which we expect to get from the Shippingport reactor. But in order to calculate these to the degree of accuracy required, we must have a firm foundation in the experiments we can make, which are with the cold reactor in this nude condition.

Moving on to the materials aspect, with each new reactor there is usually a new requirement for a material that will best fill the needs of that reactor type. This means a large metallurgical program in the development of the materials. By the development of materials, I mean developing a material that is adequately corrosion resistant, that is irradiation resistant and, in determining its physical properties, whether it can be machined, its strength, its ductility, and its other physical properties that you must know how to fabricate. Now this is not an easy job. In times past, as you know, a new alloy has taken 5, 10, or more years from its inception to where it is really reduced to practice.

It is a relatively easy thing—and I repeat this—it is a relatively easy thing to believe that an alloy with a given number of constituents would really be a useful and good alloy in a reactor, but to actually prove this—to develop all the knowledge of what impurities cause it to corrode, just how it works best, its corrosion resistance in pile and its irradiation resistance—it is a big and laborious job.

Then, having gotten the material, one must learn how to fabricate it. Fabrication is a difficult thing because there you must learn to weld. You must learn what the shrinkage and distortion is. You must learn all the many problems of rolling and fabricating so that you can, in fact, make a reliable core to be used in the reactor. We must go into the material itself from the pilot stage, where you make a small ingot, on to the production stage where many suppliers make large ingots.

Recently in something that we know almost the most about, which is the zirconium alloy—zircaloy 2, we found that when we went to large-scale production that the difference brought about by large-scale supplier production as against laboratory production produced certain inharmonies; lack of uniformity of material and this, in turn, affected its corrosion resistance. Some variations in the process had been instituted and these interfered with its purpose as a corrosion resistant alloy.

Another area in which a lot of work is done and a lot of work is needed is in the area of heat transfer and fluid flow. I think many

people had believed that water being such a common substance surely almost everything was known about its heat transfer properties, about its flow resistance in pipes even with a little steam present, but the facts are that very little is known about this. More is being learned each year, but still the data is not as good as is needed for the design of a reactor.

In addition to the development work on the core, as represented by the heat transfer, the mechanical, the metallurgical, and the physics, the rest of the plant is a big development job because essentially none of the components that we can put into a reactor plant today can be taken off the shelf. They, themselves, have many developmental aspects.

Aside from the development aspects of the components, we have the big design engineering job of coordinating all of this equipment into one powerplant to produce power—electricity or a shaft turning. Why is that so complex a job? The jobs are not larger in physical size than many other jobs that are done in the United States. I think the biggest reasons are the newness and the uniqueness of the components and the close interrelation of all these components. A reactor powerplant is closely coupled in several unique ways. The core emanates radiation and, therefore, you must shield the entire plant. This is, of course, a larger job on a submarine or a naval vessel than it is in a land powerplant because you must tie everything together in interrelating the shielding, the hull, the weight and space, and you must know what effect the components have in filtering out some of the radiation. The job must be done as a whole. You can't do parts of it and then just casually fit them together. The job must be engineered from the ground up with the entire scope of the project in mind.

Then you have the radiation heating of all the material that you use to support the core. These materials absorb gamma rays and this introduces design complications. Then in a pressurized water plant large sections of pipe are under high pressure. The whole plant acts as one unit from a thermal expansion viewpoint and you must arrange to take up this expansion, otherwise you will cause a break in the pipe and release of the fluid. Then you have the problem of radioactive contamination. The corrosion products that go through the core have radioactivity introduced into them and they go through the pumps, the pipes and the valves and you must be prepared to handle the maintenance of the plant despite the fact that you have some radioactive contamination.

Then there is that close coupling of a reaction upon the power of the reactor due to the pressure and temperature of the water. Opening a valve some place—starting a pump—can change the temperature of the water going through the core and therefore change the power. So your control must be such that those things don't happen except in the way that you predict and your overall control must be better due to the close coupling and reflection back on the core itself of all of the parts of the plant.

A reactor plant must have all of its components working in order to run. You cannot run a reactor powerplant with parts of it not working. The control drive mechanism, the instrumentation, the pumps, the valves, the heat exchangers—they must all work. This

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means that in order to get the maximum amount of information out of a plant like Shippingport you must keep it running in order to find out what you need from the core.

In building a reactor for a naval vessel we are not building experimental reactors. We are building reactors that must power the fighting vessels of the Navy. These reactor powerplants then are built so that they are rugged, reliable, and easily maintainable. They must work in fact. A submarine powerplant cannot shut down when it is on a battle mission or even when it is cruising simply because something doesn't work. You must have it so that these things do not happen.

In order to accomplish this, it has been necessary to what might appear at a casual glance to overdesign, to overtest—in order to give what we think of as maximum assurance that all of the parts individually will work and that they will work as a unit when coupled together. We have had to do a great deal of testing of components, and then test groups of components, and then overall testing of the plant. This we feel is a very important part, made doubly so, as I said, because these components that go to make up the plant are not ones that you can buy—that have been used for years and that have a long history of satisfactory operation.

For example, canned motor pumps were developed in the sizes used for the *Nautilus* and, therefore, in order to make sure that these pumps were satisfactory, a great deal of development and testing was required. The same is true of our heat exchangers, valves, particularly pressure relief valves and the pressure vessel itself which seems like a relatively simple item—just a heavy-walled vessel with a head on it—but the head required a tremendous amount of development so that it could, in fact, be built with a large number of holes in it for the control drive mechanisms and other purposes.

I have gone through the broad picture of the development problems in physics, in metallurgy, and in powerplants. I would like to call on some of my colleagues to take these particular areas and expand upon them so that you will have a better detailed picture of just what it takes in the way of, for example, the physics effort to build one of these reactors.

Representative PRICE. I think Mr. Durham has a question.

Chairman DURHAM. Mr. Simpson, this is an excellent statement. Personally, I have enjoyed listening to it. We all realize the difficulties in a brandnew development. However, is there any way you can arrive at a percentage as to the amount of conventional development that you can apply to the development of a reactor? Would you say it is 90 percent that is new and 10 percent conventional of that which has been worked out prior to this development process?

Mr. SIMPSON. With respect to the *Nautilus*, I hesitate to say that a hundred percent was developmental so I will back off just a little bit. However, there was scarcely a single item of any type that could be taken off the shelf; that had been used and could be used, therefore, in the *Nautilus*. Almost every item was developmental well in excess of 90 percent.

Admiral RICKOVER. May I answer that question, sir, because there is something that goes beyond what they did here. I can state unhesitatingly that I don't think there was a single item in the entire propulsion plant that didn't have to be developed.

Chairman DURHAM. I asked the question because I don't think people at large realize that fully. They think a lot of this work has been accomplished before.

Mr. SIMPSON. For example, even the steam plant for the *Nautilus* was new. No steam plant had ever been put on a submarine before. No steam plant, therefore, had ever run at these submerged depths. So a simple item like a condenser, which on a surface vessel operates at just a few pounds pressure, must operate on a submarine at many hundreds of pounds pressure. Take a simple thing like the safety valve. The steam system, instead of just opening and blowing the steam into the air, must open and blow it into the ocean. You can go on from there. All of the valves that we used in the *Nautilus* in the reactor plant had never been built before. The same is true of the pressure vessel; in fact, all of the components. High-pressure water had not been used in this way to any degree in the United States. High temperature water is, of course, used in boiler plants, but it is a different temperature and different degrees of corrosion are required. Therefore, the components are different in order to be suitable for a reactor.

Chairman DURHAM. Would your statement apply generally to all reactors?

Mr. SIMPSON. Yes. Obviously, they are less developmental as each succeeding reactor is built so it is difficult to assign a percentage to a new submarine today. The pumps that went into the Shippingport plant are much larger than the *Nautilus* pumps and, therefore, the mere fact of size involved a considerable development. A reactor vessel from a small vessel moved into a large one would require a different type of plate. In fact, the plate for the PWR vessel was the thickest clad plate that had ever been rolled in the United States. Therefore, many of the plates had to be thrown away because they weren't suitable.

Chairman DURHAM. Since the *Nautilus* was the first one, could you estimate on a percentage basis what knowledge which you gained in developing the *Nautilus* could be used in developing the *Sea Wolf*?

Mr. SIMPSON. I am not familiar with the *Sea Wolf*.

Admiral RICKOVER. I think I could answer, Mr. Durham. Because in a naval vessel you have to get the smallest weight and space, I would say that we did learn something about the principles, but as far as the actual development of items it was entirely different. That is not only true of the *Sea Wolf*, which is a liquid metal plant, but it is almost equally true of all the other submarine and surface-ship developments. You will find with these different projects that there is hardly a single item in one that you can use exactly in another one because we don't have acres of space to put it in. Actually, when we undertake the development of a new propulsion plant for a naval vessel—and it is practically true of all nuclear-powered naval vessels—we have got to develop all of the items individually. It is not only true of the reactor plant. It is true of the entire plant including the steam plant, the turbines and gears and so on. For example, we had to develop special turbines on the *Nautilus*. We had to develop special gears. You might ask, "Why isn't that available?" It just isn't.

Chairman DURHAM. What I am getting at, Admiral, is this. The members of this committee are often faced with a question from an

individual who says, "They tell us the *Nautilus* is obsolete so what do we have after this investment of taxpayers' money?" That is the hue and cry. Can we make some estimate as to the knowledge we have gained through the development of the first reactor? It would help us if we could have some estimate or if some estimate could be worked out. I don't know whether it can be or not. I am just raising the question here as a matter of discussion because that money is invested in knowledge.

Admiral RICKOVER. Perhaps I could answer it this way. Actually we could talk two different ways: One is about the development principles and scientific and engineering knowledge; the other is for specific items.

From the first standpoint, unquestionably most of the technology which exists in the country today on pressurized water reactor plants has come out of the efforts of this laboratory and to some extent out of the Knolls Atomic Power Laboratory.

Representative HOLIFIELD. Where?

Admiral RICKOVER. The Knolls Atomic Power Laboratory, because they have been working for several years on the radar picket submarine which has a pressurized water reactor. When it comes to individual items, however, the people who are working on commercial pressurized water plants by and large copy what has been developed because they have room to do so. The General Electric Co., in their San Jose plant, have copied the design of a PWR pump, for example. They can afford to because they have the space in which to copy exact items, the principles of which have already been developed. However, when it comes to a shipboard plant we can't do that because we have the intolerable situation of weight and space so we have to take these items and redesign them. That makes a terrific load in getting one of these projects done. One of the members of your committee asked me the question from the money standpoint several years ago. I stated then and I will state unhesitatingly again that I think there has been more advantage to American industry from the work that we have done than the actual cost of these projects. There are the developments in metallurgy, not only in zirconium and hafnium but in stainless steel. We have taken the lead in the last 2 or 3 years in developing stainless-steel technology. This will be covered a little later.

I think that is what Mr. Durham is really getting at. I think there has been a net gain to the American economy from this effort which is above and beyond any material or national gain in having these plants.

Chairman DURHAM. I think we on the committee realize that fully. We, of course, have to have something that is a selling point when we get into these big sums of money.

Admiral RICKOVER. If you would permit me, I would like to add subsequently to the record a list of these things we have contributed to the American economy.

Representative PRICE. I think that is an excellent idea. Will some of the speakers who follow cover what you have done here at Bettis in the development of new alloys and new materials?

Mr. SIMPSON. Yes sir.

Admiral RICKOVER. If that is satisfactory, sir, I would like to submit that list.

Representative PRICE. We would like to have it very much.
(The information referred to follows:)

DEVELOPMENTS IN THE NAVAL REACTORS AND PWR PROGRAMS WHICH ARE APPLICABLE TO OTHER CIVILIAN PROGRAMS

This report summarizes some of the developments in the naval reactors and PWR programs which may prove useful to others. However, the major contributions are broader than can be indicated by a list of items. For example, working out with the AEC's Safeguards Committee how to analyze the safeguards problems associated with the first reactor in the world to produce large quantities of useful power (the Nautilus prototype at Arco, Idaho); the first power reactor to operate near heavily populated areas (the *Sea Wolf* prototype at West Milton, N. Y.; the first reactor to power a ship (the *Nautilus*)—many of the precedents worked out for these problems can now be followed by others.

A similar situation exists for the development of techniques for power reactor design . A methodolgy has been worked out involving large-scale digital computers, mockup and flexible nuclear assemblies, large apparatus for testing fuel elements under simulated plant conditions of radiation, heat generation, temperature, and flow; specifications and equipment for testing all of the specially developed so-called conventional components, such as pumps, valves, and instrumentation.

The information below is grouped into three categories: Techniques and basic information, materials, and equipment development.

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I. NEW TECHNIQUES AND BASIC INFORMATION

1. Naval reactor technology handbook series

Interim and internal technical documents in the naval reactors program may not always be helpful to a person in a civilian reactor program because—

(*a*) Such documents often contain information which is fragmentary, unevaluated, or even data which later proves to be incorrect.

(*b*) Such documents usually contain military design information; the person in question may not be entitled to receive military information.

To reconcile these facts against the real need of civilian reactor groups to obtain information developed in the naval reactors program, a series of reactor technology handbooks is being prepared. Virtually all of the information developed in the naval reactors program which is applicable to civilian reactors is being published in this manner. By editing and by recalculation of sample problems, military information can be avoided and nearly all of the technology can be released. An important feature of these books is that work in each field is reviewed by people actually working in that field, and evaluated information is published rather than possibly conflicting or confusing data. The meaning of the data is also discussed.

The following handbooks have been published to date:

Liquid Metals Handbook	1st edition, June 1950; 2d edition, June 1952; 3d edition, June 1955; 2d printing, November 1955.
Metallurgy of Zirconium	July 1955.
The Metal Beryllium	July 1955.
Bibliography of Reactor Computer Codes	Dec. 1955
Reactor Shielding Design Manual	Mar. 1956.
Corrosion and Wear Handbook for Water-Cooled Reactors	June 1957.

Currently in preparation:
Naval Reactor Physics Design Manual
Heat Transfer and Fluid Flow Manual
Reactor Core Design Manual
Reactor Plant Piping Handbook
Radiological Aspects of Naval Nuclear Propulsion Plants
Hafnium Handbook
Irradiation Testing and Hot Lab Techniques
Nuclear Fuel Elements

2. Basic heat transfer research

For both sodium and water it was found at the beginning of the naval reactors program that basic data on physical properties, heat transfer rates, and pressure drops were not known with sufficient accuracy over the necessary range of operating conditions. In particular, the problem of heat transfer under transient conditions required study. Therefore, for several years basic experimental and theoretical work on heat transfer has been underway in the naval reactors program. The sodium work has been reported in the Liquid Metals Handbooks, and several new analytical methods, for example for natural convection in irregular shapes and for thermal shock caused by rapid temperature changes in the liquid, have been developed and reported. For water, better measurements of the pertinent physical properties, heat transfer rates without boiling and with the various possible modes of boiling, pressure drops with and without boiling, and limiting conditions beyond which fuel element meltdown can occur, are being studied. This work is being done both with electrically heated test sections and with specially instrumented fuel assemblies in the Naval Reactor Facility in Idaho. The variables affecting heat transfer in the reactor are now being added to the reactor physics equations so that an entire reactor heat generation and heat transfer problem can be studied as a single entity on a large-scale digital computer. These techniques should be valuable to other reactor designers. A handbook on heat transfer and fluid flow for pressurized water reactors is now in preparation.

3. Reactor physics

The naval requirement for a compact reactor of high performance necessitates that heat generation rates be calculated at many locations within the reactor core, for various times throughout the reactor life, and with various assumed casualties such as stuck control elements. A procedure for analyzing reactors in this detail is being developed using digital computers for calculations, in combination with experiments with laboratory assemblies of uranium and other materials designed to simulate, from the nuclear standpoint, characteristics of the operating reactor. Many of these techniques are now being used by other reactor projects.

In the course of this development several new physics concepts and techniques have been worked out. Some of these are listed below:

(*a*) *Seed and blanket principles.*—This is a concept whereby a natural uranium reactor, which cannot operate by itself in ordinary water, is kept going by neutrons leaking from a U–235 reactor. The resultant combination permits power to be extracted from natural uranium and also decreases the amount of control required.

(*b*) *Power flattening methods.*—By use of different concentrations of fuel and of poisons in different parts of the reactor, the generation of heat throughout the core can be made more uniform, and thus the core volume and the uranium content can be utilized more effectively.

(*c*) *Nuclear constants.*—Many nuclear constants have been measured more accurately for the naval program and the data are now available for other reactor designers. An example is the poisoning effect of xenon, a particularly troublesome fission product.

(*d*) *Epithermal reactors.*—The physics of reactors operating with neutrons of intermediate energy was largely unexplored prior to the development of the *Sea Wolf* reactors. Many of the physics constants and analytical techniques developed for it are applicable to the civilian fast reactor program.

(*e*) *Slightly enriched reactors.*—In exploring methods to obtain maximum utilization of U–238 in a reactor, a program for exploring slightly enriched reactors was undertaken by Bettis plant with help from Brookhaven National Laboratory. This program developed information and methods of analysis which can be used by other civilian reactor programs.

(*f*) *Large-scale digital computers.*—Most of the computation methods developed for naval reactors and the computer codes for implementing them are sufficiently general to be used in civilian reactor programs. A book of these computer codes was published by the Naval Reactors Branch and is being kept current by a nuclear codes group set up for the purpose by members of the American Nuclear Society. Arrangements have been made with computer manufacturers to supply punched cards and instruction books for these codes, without charge, to anyone requesting them.

4. Reactor design

Instruments have been developed to measure temperature, waterflow, and neutron flux at many locations inside a reactor core. This will permit more accurate study of how a reactor operates. Cores for the pressurized water reactor and for naval prototypes will all have such instrumentation.

The following are some particular developments in the naval reactor design field which are of possible application to civilian reactors:

(*a*) Use of airflow techniques for establishing the flow distribution through the core and hydraulic forces on control rods.

(*b*) Establishment of pressure drop characteristics of waterflow when some parts of the reactor are locally boiling.

(*c*) Development of a method for identifying and locating failed fuel elements. This required development of sampling means, identification of the influence of piping characteristics on the system, and establishment and proof testing of means for measuring delayed neutrons.

(*d*) Computational techniques for defining the shutdown requirements arising from the simultaneous and sequential loss of pumps during an assumed casualty.

(*e*) Establishment of the feasibility of and defining the conditions under which labyrinth seals can be used for controlling water leakage in the internal parts of core structures. Previous applications of labyrinth seals were generally limited to steam and gases.

(*f*) Computational techniques for including nonnuclear variations in fuel element properties in defining operating limitations of a reactor. This includes such effects as fabrication tolerances, warpage characteristics, maldistribution of flow, and uranium density variations. Both local and average influences are accommodated.

(*g*) Contributions toward understanding the phenomena associated with exothermic zirconium-water reactions, and their implications to reactor safeguards.

(*h*) Efforts to identify, measure, and take into account local neutron flux peaking caused by water channels adjacent to fuel elements, which have proved to be a highly important design limitation.

(*i*) In the general fields of heat transfer and hydraulics, data have been published from many experiments that have been conducted on flow mixing, flow coastdown, decay heat, loss of coolant, boiling, and parallel channel flow.

(*j*) Development of a mechanism which provides partial shutdown of the reactor to permit rapid recovery from inadvertent shutdown signals or easily corrected casualties.

5. Pressurized water reactor technology

The problem here was to provide a hermatically sealed system into which highly purified water could be introduced, in which continuous purification of water could take place, and which could be kept at a pressure higher than the boiling point of the hottest spot in the reactor. Build-up of radioactivity in the system outside the reactor and deposition of corrosion products on heat transfer surfaces had to be held to a minimum. The motion necessary to circulate the water, to move valves and reactor control elements, to sense and to transmit temperature, pressure, flow and position information—all of this had to be transmitted from within the system to control and power equipment outside, without violating the all-welded high pressure boundary. The particular

components to accomplish these various jobs are discussed in section III. Below are listed some of the developments of this technology which may have application to civilian reactors. This information is reported in the Wear and Corrosion Handbook published by the Naval Reactors Branch, June 1957.

(*a*) The adaptation of a bypass purification system using ion exchange resin for control of water purity in a high temperature water reactor system.

(*b*) The application of controlled alkalinity in a reactor coolant system to minimize general corrosive attack and deposition on heat transfer surfaces in a radiation field.

(*c*) Use of lithium-form and ammonium-form ion exchange resins in the purification system to provide alkalinity control compatible with the characteristics of pressurized water reactors.

(*d*) Use of dissolved hydrogen in the water to suppress water dissociation in reatcors, a phenomenon which can lead to unsatisfactory water conditions.

(*e*) Analytical methods and equipment for pressurized water reactors, including a high pressure conductivity cell and techniques for determining dissolved hydrogen and dissolved oxygen in high temperature water.

(*f*) High temperature purification media are presently under development with the objective of eliminating the need in the purification system for heat exchangers and overtemperature protection.

6. Sodium reactor technology

A new technology was built up to permit handling of radioactive sodium on a large scale at high temperatures. Methods had to be developed for maintaining high purity, insuring leak-tightness, and providing control of flow and temperature. Basic data were obtained in some cases up to 1,500° F. on corrosion, transport of radioactivity, self-welding of contacting surfaces, bearings, seals, sampling, analysis and purification of sodium, and maintenance techniques. Some of the major components developed are discussed in section III. Heat transfer in sodium was found to require new theoretical treatment, since the standard equations used for lower conductivity fluids such as water and air were not applicable. This information is reported in the 3 editions of the Liquid Metals Handbook published in 1950, 1952, and 1955. Analytical techniques for determining minute quantities of impurities in sodium were developed. Methods for cold-trapping oxides from the sodium to decrease corrosion were also developed.

7. Testing fuel elements

The most developmental, most expensive, and most critical part of a reactor plant is generally the reactor core itself. The problem of proof-testing the nuclear fuel elements is extremely difficult, since the environment of heat generation and radiation cannot easily be simulated. A means for installing pressurized water test loops into reactors was developed whereby most of the appropriate conditions could be simulated. The equipment required to achieve and control this environment has now become reasonably standardized and the technique is being followed by others. In particular the concept of initiating deliberate failures of various kinds in the fuel element to study the growth of a flaw from a minor to a serious one has proved useful.

8. Reactor control and safety

The problems of controlling a nuclear propulsion plant were largely unexplored when the first naval reactor designs were begun. Fast-acting reliable automatic control equipment was developed.

The safety problems associated with operation of power reactors had to be defined and explored. Information has been obtained on such general problems as chemical reaction rates of sodium and of zirconium with water and with air, flammability and explosiveness of mixtures of hydrogen with steam and air, and rate of heatup of a reactor when the coolant is suddenly lost. Much of the information developed during these studies has been brought together and reported in a series of reports on the safeguards analysis of the PWR plant. These reports are unclassified and will be available to the general public after they have been reviewed by the AEC Advisory Committee on Reactor Safeguards.

II. MATERIALS

1. Zirconium and its alloys

Zirconium was selected as a reactor structural material for pressurized water reactors because of its favorable nuclear properties and corrosion resistance.

In 1948 only a few thousand pounds of crude zirconium were produced in the United States. In that year only 86 pounds of refined zirconium were produced, which sold for about $200 per pound. A production plant for refined zirconium was built and operated at the AEC's Bettis plant. Steps have since been taken to get several commercial producers to begin production. Today the production of sponge zirconium is about 100,000 pounds per month, and the cost has dropped to about $11 per pound.

To further improve the value of zirconium, an alloy called zircaloy-2 has been developed. Zircaloy-2 is cheaper than pure zirconium and has improved corrosion and mechanical properties. An additional benefit of this alloy development was the arc melting technique developed by the Bureau of Mines for making zirconium alloy ingots. This arc melting technique has since been applied to titanium melting by the titanium industry. In the nonnuclear field zirconium may prove useful to the chemical industry because of its excellent corrosion properties.

To disseminate information obtained from the zirconium program, a handbook of over 700 pages was published in 1955.

2. Hafnium

Hafnium is a byproduct of zirconium refinement and had few uses when it first was separated in quantity. It was known to have excellent mechanical properties and corrosion resistance, similar to zirconium, but unlike zirconium to be a strong absorber of neutrons. Hafnium has since proved to be an excellent control-rod material for pressurized water reactors. Hafnium may also find uses in nonnuclear fields because of the very high melting point of its compounds and because of its heavy weight (greater than lead). A handbook on hafnium, its properties, fabrication methods, and other technical data, is now in preparation.

3. Other neutron absorbers for reactor control

To stretch the supply of hafnium a program was begun to develop alternate control rod materials. The principal materials studied were boron in stainless steel, boron in titanium, and silver alloys. Although pure silver dissolves in hot water, the addition of cadmium and indium to silver prevents this corrosion. These elements are also beneficial from a nuclear standpoint. The resulting alloy is cheaper than hafnium and may find use in commercial nuclear reactors.

4. Nuclear fuel materials

The naval reactors and PWR programs have worked on the development of uranium zirconium, and uranium oxide fuel materials:

(*a*) *Uranium-zirconium.*—Uranium zirconium has been developed as a fuel alloy material. This alloy has been shown to be capable of producing heat at a high rate for a long time. A large fraction of the fuel can be used up while still maintaining the strict mechanical specifications for reactor fuel elements.

(*b*) *Uranium-oxide.*—Uranium oxide has been developed as a fuel material and it will be used in rod form in the PWR core. This material has several desirable properties. It is inert and does not dissolve in water. It is dimensionally stable under irradiation. Compared with uranium alloys, it is less expensive to make and to fabricate into fuel elements.

Methods of using uranium oxide in plate form are also being studied.

5. Unlubricated moving parts for pressurized water reactors

To develop satisfactory mechanisms which required moving parts to operate in highly purified reactor water systems necessitated development of a new techology. Bearings, valves, control mechanisms, and various locking and latching devices in and near the reactor were involved. Satisfactory materials and combinations of materials for these various applications have been developed, along with equations defining the tolerable clearances, bearing loads, temperatures, torque, and other limiting criteria which determine operating characteristics.

The data on this program are reported in the Wear and Corrosion Handbook published by the Naval Reactors Branch, AEC, June 1957.

6. Stainless steel for reactor systems

A program was carried out to develop conditions under which commercially available stainless steels could be utilized in pressurized water reactor systems. Corrosion data, static and dynamic, effects of radiation and of chemical composition of the water, and other pertinent data were developed. The use of

stainless steel for this purpose has now been demonstrated and the information is being used by other pressurized water reactor plant designers.

7. Materials for handling high-temperature liquid sodium

A program for developing materials for handling liquid sodium and sodium-potassium alloy at temperatures up to 1500° F. was carried through in both laboratory tests and large-scale plant equipment. Springs, bellows, bearings, and valve parts were studied from a materials standpoint and satisfactory materials for these purposes were developed. This information has been made available in the unclassified Liquid Metals Handbooks series.

III. EQUIPMENT DEVELOPMENT

1. New vendors for nuclear equipment

Approximately a year and a half ago the AEC's Bettis plant was the only organization equipped to build reactor cores for pressurized water naval reactor plants. Steps were taken to acquaint industry with the requirements for fabricating these reactor cores in order to build up other sources of supply. The criteria used in considering prospective core manufacturers were:

(*a*) The company must have the necessary privately owned facilities or be willing to provide these facilities at no expense to the Government.

(*b*) The company must be willing to train personnel.

(*c*) The company must be willing to compete on a fixed-price bidding basis with other companies.

Today, there are five companies which are acquiring the necessary facilities, trained personnel, and capability to manufacture complete naval reactor cores. Fixed-price competitive contracts have already been let for five submarine cores, and competitive fixed-price bids for several more submarine cores of another design are now being reviewed by the Government prior to contract award.

For so-called conventional equipment, a somewhat similar path was followed. Starting with the procurement of equipment for the *Nautilus* prototype, the naval reactors program has worked toward the development of more than one source of supply for components of nuclear propulsion plants, anticipating the time when every item could be purchased on a competitive fixed-price basis.

Reactor plants for 5 fleet-type nuclear submarines (2 in the fiscal year 1955 and 3 in the fiscal year 1956 shipbuilding programs) were the first ones to benefit from this effort.

The estimated cost of these five reactor plants is $24,779,524, exclusive of (*a*) minor components and installation work which are covered by appropriate construction contracts with the shipbuilders, and (*b*) steam machinery and reactor cores which are being purchased competitively under separate contracts.

With the exception of the first core for these submarines which is being fabricated at the AEC's Bettis plant, and some plant control and instrumentation equipments for which development work was still under way, the remaining 4 cores and all other reactor plant components for these 5 submarines are being furnished on a fixed-price competitive-bid basis.

Approximately 300 subcontractors and first-tier suppliers are engaged in furnishing these 5 reactor plants.

It is expected that other reactor programs will also benefit from these actions.

2. Nuclear reactor cores

The following list includes some of the items developed in the naval reactors program in the field of reactor-core fabrication which appear to have application to civilian reactors:

(*a*) Nondestructive testing techniques for the inspection of clad fuel plates, fuel rods, and fuel assemblies. These include ultrasonic, eddy current, X-ray, and mechanical methods.

(*b*) Production methods for forging, rolling, extrusion, and other metalworking processes necessary for the fabrication of complex zircaloy shapes.

(*c*) Fabricating techniques for seamless zircaloy tubing and manufacture of such tubing for high-pressure in-pile test loops, as well as for PWR fuel rods.

(*d*) Welding techniques for joining zircaloy to zircaloy. This includes the design and manufacture of remotely operated welding chambers.

(*e*) Techniques for arc melting homogeneous zirconium-uranium fuel alloy, including the design of new types of furnaces.

(*f*) Manufacturing techniques for zircaloy-clad fuel plates. This includes cladding by roll-bonding and edge flanging techniques.

(*g*) Methods for joining fuel plates into fuel assemblies maintaining accurate spacing of the plates. These include both fusion welding and resistance welding methods.

(*h*) Standardized high-pressure hot-water and steam corrosion-testing techniques for reactor fuels and cladding.

3. Components for pressurized water reactors

Even so-called conventional components such as pumps, valves, and heat exchangers, when used in a reactor system, were found to require complete redesign and development. For example, in order to operate pumps in a pressurized water system without seals, a canned rotor pump was developed in which the rotational power is transmitted magnetically through a welded can. A similar principle is used to operate solenoid valves in the system. The major valves are powered hydraulically by the reactor coolant itself, which in turn is actuated by a solenoid pilot valve. The control mechanisms which move the reactor control elements also operate without seals. In addition, all of the moving parts and bearings surfaces in these reactors are designed to permit replacement without major maintenance. These components have been widely reported in the unclassified literature and are already used in many reactor systems, test facilities, and other systems requiring hermetic sealing of a dynamic system. The pumps are now being used as recirculation pumps in high-pressure commercial boilers, and may also find use in the chemical industry.

The naval reactors laboratories are working with manufacturers of boilers and heat exchangers to stimulate development of designs and materials for heat exchangers which can provide the high integrity essential to a reactor plant. This program is expected to have some influence on the design of conventional heat exchangers. Similar programs with industry are being carried out for pressure vessels, heavy forgings, castings, and plates.

4. Components for sodium reactors

When the naval sodium reactor work began, a similar equipment problem existed for sodium as for pressurized water, but with the factor of high pressure being replaced by one of higher temperature and a less understood chemical environment. Seals using frozen sodium as a barrier were developed. Electromagnetic pumps with no moving parts were developed for high pumping capacity against high head. Valves of several sizes and types have been developed which operate satisfactorily. Equipment of this type and the design principles behind it have been discussed in many unclassified papers and are being used by civilian reactor projects.

5. Nuclear instrumentation

Nuclear instrumentation, when the naval reactor designs were begun, was delicate, complex, and handmade. Rugged, stable, wide range, interchangeable, and maintainable equipment had to be developed. Specific developments completed or underway are:

(*a*) Development of reactor control circuitry to operate in the power range without any electron tubes.

(*b*) Use of standardized parts to decrease size, cost, and simplify maintenance.

(*c*) Development of temperature detectors for use in high-radiation and high-temperature regions.

Representative HOLIFIELD. Mr. Chairman, I would like to ask Mr. Simpson or Admiral Rickover a question in an effort to narrow the general knowledge down to a specific problem. How much of these techniques which you have developed in your pressurized water project, for instance, can be carried over into a sodium reactor or do you face a completely different set of problems—a different set of designs in your sodium or metal-cooled reactor?

Admiral RICKOVER. Yes, sir; you do. You use different material by and large with every different type of coolant. For instance, in a sodium plant you have beryllium as a moderator. We use no beryllium in water plants. You use stainless steel in a sodium plant, but the qualities in stainless steel that you want in a sodium plant are different than the qualities you want in a pressurized water plant. Sodium, for example, in noncorrosive as far as stainless steel is con-

cerned. Water is corrosive, so that in this respect sodium has an advantage. Sodium, if it touches air, burns. Water, if it touches air, does not burn. The physics is entirely different so you might say that you have two completely unrelated problems.

Representative HOLIFIELD. Do you have to develop a completely different technology when you change from one of these reactors to another.?

Admiral RICKOVER. When you change your coolant you have an entirely different problem. Of course, there are some things that you know in general about metallurgy and some things about physics, but by and large it is as different as day and night between two different coolants.

Representative HOLIFIELD. In starting a new type of reactor then, you almost have to start from scratch and go through the same painful process that you went through on the *Nautilus* or is there a certain ability on the part of people who have done a reactor to know the types of problems involved so that they are starting with a more professional approach than just coming from building airplanes, for example? The coolants and materials may be different, but you do know the types of problems so you are more efficient in handling them· You know the fields of inquiry but you still have to do the development.

Mr. SIMPSON. There are certain areas in which you get some advantage. For example, thermal reactors have certain kindred—they are cousins. A sodium reactor has a different energy spectrum, therefore the physics is radically different. However, a gas-cooled reactor, like a thermal reactor has certain similarities to a pressurized water reactor in the physics. Thus some of the information you get, some of the codes for computers are useful.

Admiral RICKOVER. We have had to make a lot of studies in each reactor project which will help other projects, particularly on materials. For example, we recently completed a study: We tried to get away from the use of helium as a cover gas. We wanted to use nitrogen instead. We have been studying this thing for 2 years and we have found nitrogen may have bad effects on account of nitriting steels. If somebody comes up with the idea of using nitrogen as a coolant in a gas-cooled plant, we have information as to the deleterious effect that nitrogen may have. There are basic things you learn and certainly any organization that has become proficient in designing reactors may develop a sort of feel for what is required. It is as though you were starting a clerk somewhere. Obviously a person who had been through high school would be better than someone who has never been to school at all. You might say you have people who are through the high-school stage so that they can understand what you are talking about. That takes a long time in this game, Mr. Holifield, to really understand what you are doing. That is the sort of thing we have to have in a laboratory of this type.

When these people put out a reactor it doesn't have a lot of acres. They have to design it exactly. If we decide that it is going to have 2 fuel elements and so many control rods, it has to work with 2 fuel elements and that many control rods because there isn't any space for any more than that.

Interestingly enough we went critical—that is, in the *Nautilus*—the new core went critical exactly in the way we had calculated. We have

to because our ships, particularly our submarines, have a limited weight and space. If we don't meet it, she can't submerge—she will sink. We are getting into this game in a very, very thorough way. We must know what we are doing to the very last thing which is something you don't have to have in a lot of other plants. So our design must be extremely accurate and painstaking.

To get back to your original question, when you put a new coolant in a reactor you have a tremendously big problem.

Representative HOLIFIELD. Does that carry over into heat transference as well?

Admiral RICKOVER. Yes, sir. Let's take gas as compared with water. Gas is normally a poor heat transfer medium. That means you have got to have a much larger pumping power for gas than for water. You have to make many calculations and this is particularly true for a naval vessel.

For a land reactor of the Calder Hall type I would design the pressure vessel as large as it could be made. I would have extra fuel elements available in case it didn't work. I would keep on adding fuel elements until it did work.

This was a very penetrating question. Every time you start a new reactor—if you start a homogeneous reactor, you have different problems than you have gotten into before.

Chairman DURHAM. How does that apply to your core?

Admiral RICKOVER. The core is going to be completely different for the homogeneous reactor than it is for a gas-cooled reactor or for a pressurized water reactor.

Chairman DURHAM. In other words, that is a new job, too?

Admiral RICKOVER. Yes sir, that is a completely new job. I think you should understand it is completely new.

Representative HOLIFIELD. Actually in place of being able to do it experimentally like the British have been doing it, you have had to cover that point of accomplishment in your laboratory so that when you did install the rod type, you had already passed the experimental state. How did you scale up your computations to know that the *Nautilus* would go critical at a certain point?

Admiral RICKOVER. That was in our basic philosophy. We say we will not go to these intermediate stages in our program. We will pick a ship that we want to put the reactor in, and we will start designing those very items. At the stage of testing we will build a prototype. That is where the prototype comes in. We say this prototype will be exactly the same as the ship, and we have got to make the prototype work.

The other approach is to start in with little things, but you do not get dimensional similitude in the reactor game. For example, if you have an automobile storage battery, from that we can go and design a submarine storage battery which has about 50 times as much volume. There are many things in engineering which can be done this way. But not with reactors.

Representative HOLIFIELD. I don't understand. Why?

Admiral RICKOVER. There are two main reasons. One is that you are dealing with phenomena. There are these little phenomena that you have going on in atoms where you are concerned with a thousandth of an inch, and just a couple of thousandths of an inch may make a lot of difference in the control and the way the whole thing works. Gen-

erally in engineering you have gross effects. Take a valve. Let's say that it is good for 100 gallons of water a minute. I can take one that is designed for 100 gallons of water a minute and I can pretty much figure out a design for one that will take twice as much water with a very good chance of success, but this is not true with reactors. The only way I can do this in a reactor is by making it larger than necessary. If you make it very big and you have lots of room, then essentially your reactor is a critical experiment and not a real power reactor. Take the EBWR. They computed they would require 48 fuel elements. They actually required 78 to make it go critical. We can't do that in a naval vessel.

To get back to your original question we build something and we test it in every way we can. For example, we ran the first pumps as much as 10,000 hours before we actually installed them in the prototype. We rigged up equipment here at Bettis. We kept on testing. We rolled them 30° from side to side while they were running. There was pitch under all of these conditions too. We tested them in a live submarine under depth-charge conditions. Congress permitted us to use an old submarine, and we installed these pumps in the submarine. We exploded a 300-pound depth charge 30 yards away. The pumps kept on working. We tested a lot of stuff that way. That is how we learned.

Chairman DURHAM. Is there any way to determine the number of neutrons in a core?

Admiral RICKOVER. We know the neutron level in a core. In the prototype of Arco we have been running tests with what we call flux wires. We insert these wires in a core and we can measure neutrons. We actually know what goes on in the core. Incidentally, one of the reasons for the considerable expense is the vast amount of instrumentation that we are putting in so we can learn from future design. We have not looked at any of our plants as jobs that you just build to make it work. We have always borne in mind that we had to develop lessons for our own future and for the future of other people in the game. This is one thing that this laboratory has done a great deal toward. We have always been conscious that while we were trying to get a particular job done we had to learn lessons for the future. We had to find out why things were happening. Naturally you never do as much of that as you want to, but there has been a considerable amount of effort and money spent to develop basic information.

Chairman DURHAM. How about the speed of neutrons?

Admiral RICKOVER. The speed of neutrons depends on whether you have a thermal reactor, an intermediate reactor, or a fast reactor. All of the pressurized water reactors that we are designing here are thermal reactors; that is, they use slow neutrons. The *Sea Wolf* has an intermediate reactor. Thermal reactor neutrons have an energy level of about one-fortieth of an electron-volt. The *Sea Wolf* has about 5 electron-volts. Fast reactors have much more than that. They may be anywhere from 5 or so electron volts up to 100,000. All of our reactors except the *Sea Wolf* are thermal reactors.

Representative PRICE. Mr. Simpson, did you plan to tell us something about the size of the laboratory and the size of your organization?

Mr. SIMPSON. Yes, sir, after the various gentlemen have talked I will describe a typical reactor project. From that I will show you the number of projects and sizes.

Before we go on though, I would like to give one specific illustration of the problem of scale-up that the admiral mentioned. If you take a small reactor similar to the *Nautilus*, it has a negative temperature coefficient. If you keep making it larger and larger and keep everything relatively the same, somewhere you reach the point where it no longer has a negative temperature coefficient, but it has a positive coefficient. Instead of the reactor having inertia and tending to shut itself down and, therefore, being safe as the temperature goes up, it reverses and the power tends to rise. It then has a possible runaway condition. At that transition point you must change the design to maintain the negative coefficient, so what you have learned in the small one does not per se enable you to design the larger one, because a leakage of neutrons out of the reactor is strongly dependent on design geometry of the reactor.

Chairman DURHAM. Then there is no way to determine the efficiency of a reactor on the basis of size?

Mr. SIMPSON. This can be done analytically to the extent we are today competent. We are not yet, nor is anyone, competent to completely describe a reactor's performance with simply analytical techniques without experiments.

Chairman DURHAM. Actually you have to build it to get the full knowledge of its efficiency?

Mr. SIMPSON. Yes, sir.

Admiral RICKOVER. The next speaker is Commander Laney, who heads up the technical staff here for Mr. Geiger, the manager of the Pittsburgh area office of the AEC. As you may know, we have civilians here and officers from the Navy who are experienced in naval engineering, helping out in the field offices. Commander Laney works for Mr. Geiger and heads up the technical staff.

STATEMENT OF COMDR. R. V. LANEY, ASSISTANT TO PITTSBURGH AREA MANAGER, ATOMIC ENERGY COMMISSION

Commander LANEY. In my remarks, Mr. Chairman and gentlemen, I will attempt to point out some of the naval characteristics of a ship which influence the problem of the reactor, the reactor plant and cycle.

Each naval reactor project here has a specific end in view. It is intended to be installed in a definite ship at some definite time in the future. Because of the fact that the building time for a ship and the building time for a reactor and the reactor plant components are different, this means that the ship is partly built—it is almost entirely designed and it is on the building ways while the reactor and the reactor equipment are still being designed. Visualize the ship sitting there—its characteristics, its length, beam, its speed, its submergence depth—all are determined, frozen. The steel has been rolled and put together. The reactor designer meanwhile hasn't yet fixed his design and his components have not yet gone into production. This means that his task is very sharply defined for him and there is a very high premium on the success with which he does it.

Much is committed, in other words, before he reaches the point of committing his material to the manufacturing shop. The reactor designer then must conceive, develop, design, and produce a reactor which, when delivered to the ship, will fit into the reactor vessel which it has never seen before. That reactor vessel is resting in a ship which is a stranger, and the reactor, the vessel, the pumps, the heat exchangers, and the intricate control equipment must, the first time they operate in unison, operate correctly, so that the ship will have the necessary amount of power to produce the speed for which he has designed and which he has to come up with.

These remarks indicate perhaps how the reactor designer is given a very specific task, a very specific chunk of space and weight, performance, and criteria to meet. Long before he knows just how he is going to do this, other things contingent on that have been done. This accounts in a large measure for the very extensive development and engineering testing which accompanies and goes along with the reactor—just because the premium on this working and working right, as designed, the first time, is so high.

While you are here today you will see some of these large-scale engineering tests and with this in mind, you will understand why they are essential to carrying out the program such as I am describing. It is also true that we are by no means sufficiently able to predict the performance of a design as we would like to predict it. There is a good deal of the basic type of information still lacking. This means that it is all the more important that the engineering or performance tests are adequately and thoroughly done. Programs such as these, which span several years in time, in which the end result—the ship operating at sea—is closely and intimately linked with the design of even the components in the plant obviously call for a very closely knit system of program control in which even the seemingly more technical decisions are directly related to their influence on the ship. Will it adversely affect its weight? Will it adversely affect its speed, its safety or reliability? We, therefore, have developed a system of program control which has a rapid response time, which we hope detects quickly and corrects any of the work of design which gets out of line and which is not directed to the objective in view.

Basically the ship operating characteristics and the powerplant functional requirements are specifications prescribed by the Naval Reactors Branch in Washington. They are the working specifications to which work here is performed. Stemming from these original design objectives and working between NRB and the contractor there are developed successively refined plant designs beginning with the most tentative design in which what is feasible has to be distinguished from what is desirable but may not be feasible, so as to obtain the assurance necessary along the road ahead. These designs are then successively refined. The components, the systems of the plant are described analytically in words, and experimental programs are devised to test them at each stage of the way. The design decisions made have to be measured against the end product and its result upon the end product. All of the major design or technical decisions which are made in these programs are made essentially by agreement among the principal participants. That is the Atomic Energy Commission, the Navy, and Bettis. All major technical decisions are based on essential agreement. If there is a strong dissent

on the part of any one of these parties, the only way we feel it is possible to resolve it is by talking it through until essential agreement is reached. On the other hand, the lesser technical decisions which derive from the major ones are made in somewhat the same way in most cases—being referred back to our principal technical source of direction, the Naval Reactors Branch.

We have here at the site a joint AEC/Navy administrative and small technical group. This small group is responsible for administering the contracts under which the work here is performed and for assuring that the work is done within the prescribed procedures of the AEC and the Navy. Also this small technical group serves as a liaison between NRB and the contractor, attempting to interpret the objectives and clarify them. We monitor the work continuously so as to assure so far as we are able that it remain pointed toward the objectives we have and paced so as to achieve them in time.

Representative PRICE. Mr. Durham has a question.

Chairman DURHAM. Commander, I understood you to say that you have the hull of the ship before you begin designing or before you have knowledge as to how you can develop the reactor in a ship. Do you think that would apply to a plane as well as a ship?

Commander LANEY. I don't know the answer to that, Mr. Durham. I am not familiar with the manner in which planes and their engines are designed. In the case of the ship, the present building time for a submarine is perhaps 3 to 3½ years. That is good building time. In order to put off as late as possible the time when we freeze our reactor design, which is desirable to get the best reactor, we wait until the ship is a year or a year and a half along. Since we can build a submarine-type reactor in 12 to 14 months, we use that intervening time not to freeze the reactor, but to improve it. It is for this reason that the reactor goes into its manufacturing period after the ship has been completely committed and is in its principal characteristics fixed.

Representative HOLIFIELD. Mr. Chairman, I want to ask one question. Probably this question should go to Admiral Rickover. Could you explain very briefly what the composition of the Naval Reactors Branch in Washington is? I know you are the head of it, but how many people do you have? How many Navy people? How many civilians? What, in general, does it take in the way of qualifications from the Navy side to get in that Branch?

Admiral RICKOVER. As you know, the organization is such that my primary duty is in the Commission and I work for Mr. Davis, who is the Director of Reactor Development. I head up the Naval Reactors Branch. Our system of operation is quite different than any other branch there. We are not just building reactors. We have to build reactors, as Commander Laney has explained, that must fit in ships which have already been started. The Navy wants them to make so much speed which means so much horsepower so we are very limited. There are a lot of things we can't do. We have to work harder to make it fit.

The technical direction of our program comes from my organization in Washington. We make the more technical decisions as Commander Laney has said. Where there is an argument we have to fight it out. There has never been one time in this game that we have ordered anyone to do anything. Of course, ultimately you get to

questions where policy decisions are involved and then I make the final decision. That is where you do one thing or another. Ultimately, somebody in life has to make those decisions.

We have about 90 people in the Naval Reactors Branch. Most of them are very young. Several years ago when I started to hire people for our organization I found there were very few people who were qualified for our work. By "qualification," I do not mean, necessarily, their technical ability, but the desire to work long hours and to be dedicated to the job as well. At the state we were in we had to get people of that kind. So I came to the conclusion that first we should have a long training period. As a result of that the Commission finally set up the Oak Ridge School of Reactor Technology. We were instrumental in getting that started. There is no one in my organization who was not given special training. Everyone who comes into my organization must receive this special training.

We adopted the procedure of getting only young people. We get the best graduates from universities in the country. I have arrangements with deans of the various engineering and scientific schools whereby they recommend their best people. They come in for an interview. I am talking now of people coming from universities. They are interviewed by a board of four people. Each member of the board interviews them separately. Then I interview them. There is not a single person who comes into the Naval Reactors Branch, except secretaries, who do not have to go through this procedure. Our rate of acceptance even of these people who are so highly recommended is about 1 out of 4.

The same thing applies for naval officers. No civilian or naval personnel are ordered into this program. They are all selected. Admiral Holloway, Chief of Naval Personnel, realizing the importance of this program to the future of the Navy has made an exception to the normal procedures. He permits people to come in for an interview. We get engineering duty officers in once a year. Out of an application list of about 40 or so engineering duty officers, a board screens their records and recommends 15 or 16 to come in for an interview. They go through this process I have described. We will probably take 4 or 5.

Most of the officers in our program are young officers—Reserve officers—who have agreed to stay on for 4 years instead of the normal 2 or 3 years. We have been successful, in many cases, when their tour in the Navy is over in that they shift over into civil service. This is really one reason we take these young people in. We feel it is essential to get smart young people and train them in our way of doing things. I think it has worked out very well.

Representative HOLIFIELD. You are not reaching out then for topflight scientists. Actually you are training your own.

Admiral RICKOVER. A lot of topflight scientists are not topflight scientists. A lot of topflight scientists are that by reputation only. We can't afford to have people around who have reputations who don't work hard. We would rather have people who work hard and don't have the reputations. No, sir; we have been rather disillusioned.

Representative HOLIFIELD. This would indicate, then, it is on the capability to direct men into a certain field rather than to rely on the basis of what they had already accomplished in that field; would it not?

Admiral RICKOVER. If we get in people with more experience it takes too long to have them unlearn the bad things they know. We haven't got time for that. So we have come to the deliberate conclusion that it is best for us to take young people in who have not yet been out in industry and have learned the way industry or other organizations do things. We have our own way of doing things. A lot of people don't like the way we do business and we are very well aware of that, but there is no one in my organization who can't get out and get a job at a much higher salary. Very few of them leave though, so that is the proof of the pudding. I don't know whether I have answered your question.

Representative HOLIFIELD. It gives me an idea of the type of branch you have.

Admiral RICKOVER. I would like you to come up some time. I know you are all interested in education. I would like you to meet some of these young people, talk to them and hear what they say.

Representative PRICE. Thank you very much, Commander Laney.

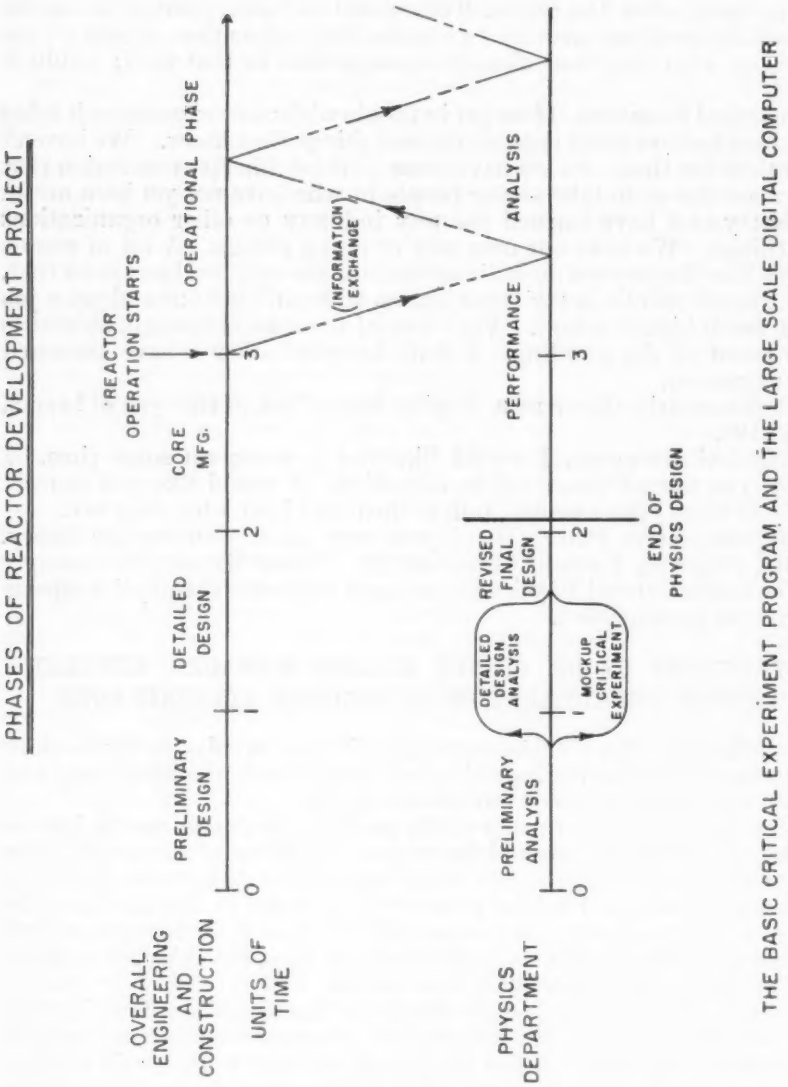
Mr. SIMPSON. I would like to ask Dr. Sidney Krasik, the manager of the Bettis Central Physics Department to discuss the physics aspects of reactor development.

STATEMENT OF DR. SIDNEY KRASIK, MANAGER, CENTRAL PHYSICS DEPARTMENT, WESTINGHOUSE ELECTRIC CORP.

Dr. KRASIK. Mr. Chairman and gentlemen, we plan today to show you some of the interesting things we have here at the laboratory and to tell you how we carry on our reactor design.

You will find a great many of the problems in the reactor design are centered and focused around the physics problems of a reactor. One of the things we want to show you is our critical experiment facilities. I thought perhaps I might take a few minutes to explain how the physics design of a reactor is accomplished, how it fits into the overall design of a reactor plant, the problems we face, the things we can do and the things we hope we will be able to do.

Actually it might be just as simple for me to make a few sketches on the board here and talk informally. Suppose we take the duration of a reactor project as being three units of time with a unit of time being more or less a year or so. This is the stage of completion of the project. The reactor core is now inserted in the ship and it is ready to go into operation so that is the operational phase of the reactor project. This is the engineering and construction phase. Something of the order of a year is associated with the core manufacture and installation in the plant. Another unit of time more or less of the order of a year is associated with the detailed design; that is the working out of the actual detailed mechanical problems. There are tremendous problems that have to be worked out in the preparation of the drawings—the release of these drawings for procurement of components.



There is left open approximately one unit of time on the order of a year for the preliminary studies which essentially fix the nature of the project. As Commander Laney told you it is about this stage of the game that the characteristics of the vessel have been fixed into which this reactor component will go. The freedom then which a reactor designer has; the freedom which a physicist has, is very limited. Indeed, all we have is this time here to decide how the reactor of which we do not yet have a good picture is going to work in that plant; how it is going to meet the final weight specifications; how it is going to fit into the space that is allocated and perform as predicted.

Let's take a look at this from the physics point of view. There have been several questions asked. Mr. Holifield asked a question about

scale up and similitude. I would like to go into that a little bit by indicating how the physics design is accomplished. The fact of the matter is, as Mr. Simpson has said, that we really don't know enough to sit down with pencil and paper and slide rule, a desk computer or even a larger automatic computer. We simply do not know how to sit down and calculate the properties of this reactor. We don't have that knowledge. We don't have that understanding of the way the reactor will operate.

The way that is accomplished then is sort of like this. This is the physics part of the overall reactor design. This is the overall reactor design. This is the physics part of it. You start out by making survey studies—trying to explore in a very rough fashion what you can do. You may spend some months doing that.

As you begin to see what it is that you are going to be able to do, what you are going to be able to meet, you can actually go into the preliminary design phase in which you begin to draw some pictures of what this reactor is going to look like. You can begin to make sketches of its size. You know what size reactor vessel it must fit into—dimensions and so on.

As soon as we have reached that stage we then proceed to go into a physics experiment which is an essential part of this design procedure. This physics experiment we call a critical experiment. It represents, as nearly as we can tell at this stage of the game, a nuclear mockup of the final reactor as we visualize it. Obviously at this stage of the game we don't know what the reactor is really going to be like so we begin this experiment with some degree of flexibility so it can be changed and modified as we learn more about the reactor.

At the same time, in order to proceed and gain as much time as possible, we actually go into a detailed analysis of the design on the assumption that we do know how to do it. That is rather than going into a detailed analysis and then into a critical experiment. Then correcting the detailed analysis, we carry them on in parallel in order to save something approximating a year in this overall procedure.

When the critical experiment—and we hope to show you several of these today—is in operation, we begin to get information which then gets put into the analytic part of the job. After, say, 8 or 10 months when the critical experiment has been constructed and it is ready to go, we find out we have made some pretty bad mistakes so we begin working back and forth between the detailed analysis and the critical experiment.

Then we go into the revised final design. This is the final design we make, and this has been released for manufacture. So you might say that as far as the physics design of the reactor is concerned, there was precious little flexibility back here even, because all of the characteristics—the size and so on—have been fixed and by the time you reached this point there is no further influence we can have on the design.

It would be a very serious mistake to stop that effort at this point. What really is needed is a followthrough on the effort and this stage which we might call the performance analysis. That is we continue the physics work. Now that we know what the reactor is going to look like, know its shape and size and some details of design, we actually begin to study in considerable detail what this reactor will

actually perform at. It may be at this particular stage of the game we can uncover a bug. If so, we are in a far better position to correct it than we would be if we waited until the reactor went into operation.

As soon as a reactor operation begins, the operational lifetime for performance, efficiency, and so on gets back into this. This performance analysis of the reactor, this followthrough on the project is an extremely important part. It is here you can make a great deal of progress for your technology. I might even cite an example. Admiral Rickover mentioned the *Nautilus* core. I think it is noteworthy that the principle that was incorporated which extended the lifetime of that core had, in effect, been suggested by a member of Admiral Rickover's staff. The suggestion was originally made and presented late in 1952, as I recall, after the first *Nautilus* core had been completed. There was nothing we could do about incorporating it in the first core then, but we proceeded to factor the information from the *Nautilus*—the Arco operation into that and during 1953 that principle was examined analytically. It then was incorporated into the prototype. That prototype was fully tested in the plant at Arco and now it is ready to be used in the *Nautilus* and do demonstrate its worth.

Chairman DURHAM. I have a question at that point. I suppose your analysis applies to all types of power reactors as well as to the *Nautilus*. Would it apply to all reactors?

Dr. KRASIK. If the procedure that is carried out in determining—in developing the reactor is the philosophy which we adopt here; namely, to make this time as short as we possibly can.

Chairman DURHAM. That is the point of course which disturbs us all. I suppose Westinghouse hopes to get into the position of selling reactors at some stage of this game. Looking at it as a hardheaded business concern which wants to purchase a reactor, how are we going to sell him that reactor on the basis of that kind of analysis? That is on the basis that all propulsion systems have to be determined more or less on the end product. You can't tell this concern whether or not this reactor will perform; can you?

Dr. KRASIK. No.

Chairman DURHAM. As I understand this analysis, you have got to go to a point where there are large expenditures of funds by somebody before you can guarantee to that purchaser that he is going to get performance out of the reactor?

Dr. KRASIK. That is for a developmental reactor.

Chairman DURHAM. That is right.

Dr. KRASIK. This analysis would certainly apply to the Shippingport plant where exactly the same type of development program is under way.

Chairman DURHAM. Here is my point. At the present time we have many companies throughout the United States looking at these things, coming in and making applications to the Atomic Energy Commission and starting in a small way. I don't see how we can ever sell a man a reactor on the basis of your analysis. If I was sitting on the board of directors of some company, I would consider this as a hardheaded businessman.

Representative PRICE. Doesn't this apply only to the first of any type of reactor?

Dr. KRASIK. What I wanted to emphasize, Mr. Durham, is that this is the way to carry out the development of the first plant of its class. This is the way the first Shippingport plant would be carried out. This is the way a new and advanced core for Shippingport might be carried out. It would not, however, apply to a duplicate plant in which all of the technology, all of the information developed here would be made available. Once you have reached this point and you know what this reactor will do you can copy it without doing any of this.

Chairman DURHAM. I realize that. Of course we are at a point of development in this country of having nothing but Shippingport at that point, you might say.

Representative HOLIFIELD. And where every type of reactor that is proposed must go through this uncertain and unpredictable stage and then operate it after you have completed the work. It has got to be operated over a period of time before you get a history of performance.

Dr. KRASIK. Exactly.

Admiral RICKOVER. We are still learning from the plant out at Arco. It is our most valuable tool. Again, let's go back to the dimensional similitude problem. The think is completely different than any conventional apparatus. You can build a turbine. After the first turbine worked around 1880, for practical purposes it was relatively easy to build a larger one. You didn't have to go through this. There were details you had to work out such as better manufacturing of buckets and fastening of buckets and the wheels and so on, but you didn't have to go through this. I don't know of any other scientific and engineering game where you have to go through this process.

Representative HOLIFIELD. You have stated that you started within the limitation of the whole—of the ship. Commander Laney explained that. Is there some advantage and if so, how much, to starting a new type of reactor without that limitation? I am thinking now of a new type of land-based power reactor. What is the advantage of not having to conform to a specific space?

Admiral RICKOVER. If you want to get a job done and have it done on time and have it work, then you had better tie the guy down within boundaries. You have to say, "You have got to produce a certain thing in a certain time." Otherwise he is going to take easy, dilatory methods. I think you will ultimately get more progress—much more progress out of this hard regimen than you get where somebody just builds something.

Representative HOLIFIELD. A hard regimen in performance and in time?

Admiral RICKOVER. Over everything, sir. That is the only way you are forced to find out what really goes on in this reactor.

Representative PRICE. It is better for the morale of your organization if they are working on a schedule.

Admiral RICKOVER. Better for the morale of the people who are working, but not for their wives and families, as I think some of these people will attest. However, that is a basic principle in performing any work of this kind. If you tell people to just build a reactor and, to use a figure of speech that they have got acres of space, they can go along and do anything. They are not pushed. When they try it out,

and if it doesn't work, they say, "We will do this and we will do that." But when you force scientists and engineers to stick to something that has got to work in exactly that way, then there is something happening every day and night. They have got to find out why as Dr. Krasik has been telling you. He has got to find out why these things are. We give him such tough limitations in space and in weight that he can't possibly do this unless he really learns why. That is the reason we are developing a science of reactors and reactor technology because we have had to find out why it works.

Chairman DURHAM. I was impressed by the statement of Commander Laney when he said that every reactor here was designed for a useful purpose.

Admiral RICKOVER. For a specific purpose.

Chairman DURHAM. In other words, something you can put in the storehouse.

Admiral RICKOVER. It either works or it is junk as far as we are concerned.

Representative HOLIFIELD. If you were designing it for a land-based powerplant, can you not tolerate more latitude in size?

Admiral RICKOVER. Let me answer that. No, sir. The thing that dictated the power output of the PWR was the maximum size of the pressure vessel that you could make. That was the largest one that American industry was capable of making. Incidentally that determined the basic design in the Calder Hall plant, also. They built what at that time was the largest pressure vessel for that pressure that could be built in England. Once you do that, the next thing you want to design and get is the maximum amount of power output you can. Your volume is fixed.

Representative HOLIFIELD. In this case your limitation was the technology of building the pressure vessel, just like in your submarine it is the space in the hull?

Admiral RICKOVER. That is right. I could have taken a different approach and said, "Fine. I have got the largest pressure vessel. I will just build a reactor. It will work and we will get out of it what we can." We didn't do that because we not only knew when we started out the maximum size of the pressure vessel, we also set the power for it. We didn't have to tie ourselves down, but we did tie ourselves down. Is that point clear?

Representative HOLIFIELD. It is clear.

Admiral RICKOVER. We tie everybody down because the natural human tendency is for everybody to create some kind of monopoly—that is to be let alone. We think that is bad—to let people alone.

Representative PRICE. Does that mean the maximum capacity of a pressurized-water powerplant in the future will be limited by the maximum size of the pressure vessel?

Admiral RICKOVER. No, sir; it does not mean that at all. When we said 60,000 kilowatts of electrical power, we wanted to give a figure that we thought we could meet. We are designing a new core based on a great deal of information that we have learned from the first one. We are designing a new one here which we think will give about a hundred thousand out on the same pressure vessel. There are many other things we have learned that we can do. Perhaps we can stand some amount of boiling in the reactor. Perhaps we can increase the size of the pressure vessel by learning how to get down to lower

pressures. There are a lot of other things. But basically the thing Mr. Holifield was asking about is the real major principle and how you go about doing the job.

Representative HOLIFIELD. I was trying to find out if the power-station people are going to be bound by limitations of one type or another the same as you are.

Admiral RICKOVER. Yes, sir. The General Electric Co. when they are building a reactor with only 1,500 pounds pressure—whatever it is—they are also bound. They are making the largest pressure vessel they can with 1,500 pounds pressure so they have already got that fence right there.

Mr. SIMPSON. There is another facet to that, sir, that I would like to bring out. Not only is there the limitation of the size of the vessel, but strange as it may seem, the actual design, manufacture, and installation of the pressure vessel takes more time than getting the core so that we have ordered and started cutting metal on the pressure vessel and even if we could have built a larger one, we were already building the one of that size.

Representative HOLIFIELD. You were committed.

Mr. SIMPSON. We were committed. Before the reactor design had reached the point where we knew as much as we wanted to about the power you could get out, the metal was rolled for the pressure vessel and at that point you can't change.

Admiral RICKOVER. It took 2½ years to make that pressure vessel.

Mr. SIMPSON. The only limitation of the larger vessel you could build is the limitation of the vessel you did build.

Admiral RICKOVER. That is the only way you can do it—if you set yourself a goal that you will have something working by a certain time. The other way you do it is to set a bunch of people designing cores and people designing a pressure vessel and sometime, maybe 2 or 3 years after they started, they get together and find they are away off. They would have to compromise at that time and you have to start all over again. It might take you 10 or 15 years before you get a reactor. You have got to set limits at some time and work to them or you will never get there. If you are working with small units, you can overbuild them. You are not concerned with the exact power you get out, particularly if it is a small order of power. When you start to work with large blocks of power or in cases where the reactor has to perform exactly, you sure have to be tied down. That is what really makes the trouble in this game. Outside of that it would be a very fine game to be in.

Chairman DURHAM. Suppose somebody comes to Westinghouse now and says, "We want a reactor that will produce 200,000 kilowatts of power." At what point could you tell that person that his plant would operate?

Dr. KRASIK. If this were the first plant of a type?

Chairman DURHAM. You have built a plant here at 60,000 kilowatts. Then someone comes in and says to Westinghouse, "We want 200,000 kilowatts."

Dr. KRASIK. Having done Shippingport and having operated the Shippingport plant we could probably now give a fairly good estimate back in here of what the feasibility would be of a 200,000-kilowatt plant.

Admiral RICKOVER. He said "feasibility" though. Be careful.

Chairman DURHAM. I am trying to get to the point where we can sell some of these.

Representative HOLIFIELD. You would be selling "feasibility" then if you actually went into the market to sell it. You wouldn't be selling "actuality."

Mr. WEAVER. This would be true, Mr. Holifield, until we have operating experience with any one of these plants.

Dr. KRASIK. I would like to add just one word to what has been said about setting the goals and setting the limits. Actually the important thing in reactor development is to explore the technology to find out what you are really up against. If you go down through a valley like a wandering river and take the easy place at each turn, you would not know what your limits are. You have to run up against the real limitations of this problem in order to find out what is going to stop you from doing something. I think from that point, quite apart from the time scale which I think you appreciate, the setting of goals is an important part of this job.

Chairman DURHAM. I think we are all trying to find out exactly where we are at in the development of these reactors. It seems from your statement that we are still in the development stage.

Dr. KRASIK. We are in a very preliminary development stage.

Chairman DURHAM. Preliminary?

Dr. KRASIK. Preliminary and it is quite unsatisfactory to all of us to go through as cumbersome and time consuming a process as this to get to a reactor state. All of us are straining to do something to eliminate this prolonged elaborate procedure.

For example, this critical experiment—quite apart from the money that it costs to build, and it is a very formidable sum of money indeed—takes somewhere on the order of 10 to 15 months in the schedule to construct. As you will see from your visit later today, it must be a rather good duplicate of the plant of the reactor that you intend to build.

Chairman DURHAM. When the Shippingport reactor is completed and operational, will it still be in the preliminary development stage?

Dr. KRASIK. We are trying to do something about this, sir. We are trying to develop the reactor physics to a state where it isn't an art where somebody guesses and puts in a lot of costly time-consuming experiments. We are trying to do a different type of critical experiments, which we will show you, and which are basic critical experiments. From these we hope to get not what is the overall properties of the reactor, but what are the individual things that contribute to these properties. Furthermore with our large scale digital computation ability we are hoping to advance the theoretical so that the combination of these two will in the course of, perhaps, 3, 4, or 5 years enable us to eliminate this completely from the reactor development schedule and to start in at a survey study. This would give you the flexibility at that stage of the game to predict what the reactor is going to do at 10,000 hours of operation. This we must be able to do. This is one of the important things which we feel is our obligation.

Represenative HOLIFIELD. Can this sort of thing be done now, say, in an automotive engine—the airplane engine?

Dr. KRASIK. I am not familiar, sir, with those engineering problems.

Admiral RICKOVER. You don't have the many variables in the automobile engine or the aircraft engine that you have here. It is not

inherent in the thing. You never had it even back during the days of the Wright Bros.

This is the most difficult thing to explain. Perhaps I can't explain it well, but really we are dealing with entirely different phenomena. We have to set up science and technology which doesn't exist, and we are attempting to do that. That is why we have these large computation machines. By using these machines, perhaps in 3 years from now they may develop the beginning of a science of reactor technology.

I think, perhaps, with all the talk that has been going on about reactors, people have the idea that reactors are much further advanced than they are. They are not as far advanced as most of the public would think they are.

Representative HOLIFIELD. In other words, you are lacking in a lot of the basic——

Admiral RICKOVER. Basic technology.

Representative HOLIFIELD. On which to base a really sound production.

Admiral RICKOVER. That is right. We cannot do that yet. However, even though this laboratory is one of the best reactor laboratories in the United States from the standpoints of experience in designing and building reactors, and number of trained people, they cannot yet predict anything. The man who is in charge of this is telling you right now that probably he won't be able to even 3 or 4 years from now.

Representative HOLIFIELD. Then when these people come before us and predict they are going to get 6-mill or 11-mill power out of a completely undeveloped reactor, they are just guessing?

Admiral RICKOVER. You can dignify it by calling it guessing.

Mr. SIMPSON. There are two ways to design anything. One is by really knowing basically what you are doing in designing and the other is by experence and rule of thumb. With the gasoline engines they built so many of them that they built up a backlog of experience. You don't quite know why it works. In designing a circuit breaker, you don't quite know why it interrupts, but you have done so many of them that you can modify it a little bit. If you start counting the number of power reactors that have operated for long periods of time, it doesn't take very long because there are so few. So the rules of thumb, the experimental data to just give you a broad background to build on is lacking. Lacking that, you must know more of the basic science of building reactors and do more of this preliminary design work in order to do it. So the day when we have built hundreds of power reactors, a lot of people will be able to design them by rule of thumb too, but that is a long way off.

Admiral RICKOVER. We know more about what goes into a reactor design today, I think, than most automobile engine manufacturers know about the design of their engine. We have to. They have built, maybe, 100 million automobiles in this country and they have minor changes from year to year in the engines. They are not confronted with a problem of mass safety either. That is another thing. We can't just say that we will take a chance and do something. We have to be absolutely certain that this thing will work and that it will be safe.

The costs are tremendous. The man who designs a new automobile engine is not investing a hundred million dollars and it doesn't take many, many years to do it. So you have all of these imponderable

things that weigh on you here. We do not yet know why we are doing certain things in design. We were quite surprised when the prototype for the *Nautilus* worked as well as it did. We didn't know how it would work. We were very much surprised.

Representative PRICE. I was interested in your comment a moment ago on the cost per kilowatt. Representation has been made to us that at least one reactor in the power demonstration program will produce electrical energy from 12 to 14 mills or a maximum of 16 mills per kilowatt immediately upon the start of operation. Can you explain the difference in that optimism and the pessimism that you have just indicated on that point?

Admiral RICKOVER. I could only answer it this way. About 2 years ago we had a seminar on the PWR. One of the issues which came up was whether we should tell what the costs were at that time. It worked out to be 52 mills. I insisted we should say this publicly. Today it is more than 52 mills. I don't know the exact figure. It might be 65 mills.

Of course, one gets engrossed in his own work and he pretty soon begins to think he is pretty good and no one else knows anything. In order for somebody to turn out a reactor which will produce at 14 to 20 mills, he is going to have to build one a lot better than we now have or know how to build.

Representative PRICE. You know all of the reactors in this power demonstration program. Can you think of one right now which in your opinion could accomplish this?

Admiral RICKOVER. I wouldn't buy any stock in any company which guarantees to produce power at that rate. If you have any extra money, I would advise you to invest it somewhere else.

Representative PRICE. It would be a conflict of interest if we were to invest in it.

Admiral RICKOVER. I am just trying to tip you off. I would not invest money in any reactor group that claims it can do this. I think Mr. Davis, himself, has said he doesn't expect atomic power to be competitive until about 1980——

Mr. DAVIS. No! No!

Representative PRICE. It would be pretty close to being competitive. Do you even expect to do that for a while?

Admiral RICKOVER. There are a lot of other people working on this and maybe they have got some secrets or tricks. I wouldn't know how to do it. I don't know how. Maybe other people do. I obviously can't talk for them. My personal opinion is that I would be inclined to be doubtful.

Representative HOLIFIELD. Of course I have been doubtful all along on this. I haven't been carried away by any of these predictions myself.

Admiral RICKOVER. I think you could ask people, "Why are you going to do it so much cheaper than the PWR?" Maybe we could learn how to design it better, how to operate it better, and have better people doing it. We don't know how.

Representative PRICE. It could be a different system of bookkeeping.

Admiral RICKOVER. That helps too. You have another thing also. What credits do you get for plutonium? What do you charge for fuel? This came up when I was in England. They said they were

putting out very cheap power with the Calder Hall reactor. I said, "Your plant cost so much to build. It costs so much to build in the United States and it is not much off from the power of the PWR."

I said, "I am not a mathematician. I am not an economist, but it seems to me if the two plants cost about the same to put up, why do you get this vast difference in cost?" It is all Government operated. They don't have depreciation charges and so on.

Representative PRICE. What did they say it cost?

Mr. DAVIS. Calder Hall, about $45 million.

Admiral RICHOVER. $45 million, but if you took it on American costs to build, it would mean may be another 50 percent more.

Mr. DAVIS. We had some estimates made of how much we think it would cost to build a similar reactor in the United States. The best guess we have is that it would cost perhaps 50 percent more to build a Calder Hall type of reactor in the United States just because of the difference in labor rates. This would make it of the order of close to $70 million—somewhere between $60 and $70 million.

Admiral RICKOVER. You run around the same and yet they say that their power costs are about a third or fourth of ours.

Mr. DAVIS. I think you have to point out that the costs they are talking of are for Central Electricity Authority and not for the Calder Hall reactor. When they talk about 7 mills they are talking about Central Electricity Authority reactors and still on this different accounting system. They have never really said, except by indirection or just letting people believe it, that there might be 7-mill power from the Calder Hall reactor.

Admiral RICKOVER. I would say, in general, that you cannot expect anywhere in the foreseeable future, say 10 years—I don't like to go beyond 10 years—that you will have an atomic powerplant that would be competitive.

Representative PRICE. Do you think it would get close to being competitive within the next 10 years?

Admiral RICKOVER. It should, because we are learning a lot and, also, the cost of fossil fuel is going up. If there is to be a real future in atomic power, it is bound to be that way sometime. I think to sell atomic power on the basis that you are going to save money is just like the argument about putting atomic power in the Sahara Desert. I say that is a good way to build railroads. If you want to build a railroad, decide to put the plant there. Then you have to build a railroad in order to haul in the materials for the atomic powerplant. It is sort of like going around in a circle. So, one way of developing the railroad industry is to put reactors in places like the Sahara Desert.

Representative PRICE. What do you think would be the cost per kilowatt-hour of the Shippingport project.

Admiral RICKOVER. It should be considerably less, because we expect to get more power out of it, if for no other reason. We expect to get about 100,000 kilowatts out of the second core instead of 60,000 for which the first core is designed.

Representative HOLIFIELD. You could do it more quickly without this research work?

Admiral RICKOVER. We still have to do the research work, because it is a different reactor, but we have got the plant there. We just put a new core in.

Representative PRICE. What do you think the difference would be?

Admiral RICKOVER. At the time, we estimated 52 mills for the first core, I believe. We estimated 39 mills for the second one.

Mr. SIMPSON. The second core.

Admiral RICKOVER. Then we estimated for the third core that we might get down somewhere around 14 mills. That is for a new plant—building a new plant. We would use all of the lessons we have learned. Today I wouldn't be that optimistic.

Representative PRICE. That is the third core?

Admiral RICKOVER. The third core would be the first core in the second plant.

Representative PRICE. What was the figure?

Admiral RICKOVER. We gave that figure 2 years ago as 14 mills. Today I would be inclined roughly to double it.

Representative PRICE. Would that indicate this plant at Shippingport would not be as efficient as some of the claims on some other plants?

Admiral RICKOVER. Any plant you haven't built yet is always more efficient than the one you have built. That is obvious. They are all efficient when you haven't done anything on them. They are in the talking stage. Then they are all efficient. They are all cheap. They are all easy to build, and none have any problems. That is quite correct. They do not have any problems at that stage.

Representative PRICE. Have you finished, Dr. Krasik?

Dr. KRASIK. I think I have essentially concluded my remarks.

Representative HOLIFIELD. I hope you will pardon our interruptions. I think we can learn more by asking for information as we go along, and that might be the best way for us to learn.

Representative PRICE. I would say your fine presentation led to the questioning.

Representative HOLIFIELD. Mr. Chairman, I would like to have this presentation given before our full committee sometime, because this has given me a better concept of the breakdown of the time schedule than I have had before.

Representative PRICE. That is a good idea.

Mr. SIMPSON. Mr. Chairman, I would like to have Dr. Lustman, who is the manager of the metallurgy department, say a few words on the metallurgical aspects of reactor design.

STATEMENT OF DR. BENJAMIN LUSTMAN, MANAGER, METALLURGY DEPARTMENT, WESTINGHOUSE ELECTRIC CORP.

Dr. LUSTMAN. Mr. Chairman and gentlemen, as Mr. Simpson and Dr. Krasik have mentioned, once the engineering design and fabrication requirements of a specific reactor are fixed, the fuel and cladding material are then fairly well chosen. However, once this choice is made, an entire spectrum of materials development problems arise which require solution before the reactor core could be considered to be feasible. I will only give you a few of the most important type of development problems.

For example, the zirconium and zirconium alloy cladding developments—the technology which was developed in the course of the construction of the *Nautilus* core can be applied quite directly to the

construction of new submarine cores or to the A1W core of the large ship reactor.

Representative HOLIFIELD. What is the A1W?

Admiral RICKOVER. That is the aircraft-carrier project.

Representative PRICE. Let me ask you this question before we get too far along. Do you have any work here at all on the merchant-marine reactor. Do you cooperate in any way with that program?

Admiral RICKOVER. We make available the information we have learned.

Dr. LUSTMAN. In connection with his cladding problem for the PWR, pressurized-water reactor, simply a change in the design from the shape which is used for the *Nautilus* and for these other reactors required an extensive materials-development program and close cooperation an liaison between Bettis personnel, who are familiar with zirconium fabrication technology, and fabrication companies who are familiar with the fabrication of metal tubing.

On fuel materials, Bettis has taken the lead in the development of two essentially new types of fuel material. One of these is uranium oxide, which is used in the pressurized-water reactor for Shippingport. At the time uranium oxide was chosen as the preference fuel for the pressurized-water reactor, only a slight amount of laboratory-scale information was available on this material. Many of the properties which were necessary to assess the feasibility of this material as a fuel were not available. Furthermore, the technology had not been developed to permit the fabrication in shapes from uranium oxide power into production quantities.

Such basic questions as the reaction of the uranium oxide with zirconium alloy cladding, the conditions of water chemistry necessary to maintain uranium oxide in contact with water, thermal conductivity of uranium oxide—all of these questions had to be investigated and determined before the feasibility of such a material could really be supported.

In connection with a question asked by Mr. Holifield, during the course of the PWR development we did work on a similar type of alloy in the same class—uranium molybdenum alloy. The technology which was developed for this alloy is being used by the Detroit Edison group in their reactor.

Chairman DURHAM. At this point, which emits the most gamma rays—oxide or alloy?

Dr. LUSTMAN. I think it is the quantity of uranium and the amount of uranium burnt up which controls the radioactivity of the material. Large development was required for the alloys because of the lack of knowledge which existed prior to their investigation here. There were all sorts of factors—hot water corrosion resistance, thermodynamics stability of the material, specifications from purity contents, method of melting, casting, rolling, bonding with zirconium cladding—even the development of sources of metal to use as an alloy and, in addition, of suitable purity—all of these questions had to be answered. Furthermore, they had to be answered within the time period, which Dr. Krasik outlined, which is available for the development of the reactor. Certainly, many development questions have had to remain unanswered because this time period is much too short. Decisions have to be made and concurred with between Bettis per-

sonnel and Naval Reactors Branch technical personnel to permit the job to go on within the required scheduled period.

Another important field is the field of evaluation of fuel elements and fuel materials under reactor operating conditions. The greatest uncertainty in the materials field, I believe, resides in this area. This is also the widest area of research and development in reactor core materials which remains today. This uncertainty is because to a large extent there is no theoretical background which permits prediction of the effects of radiation on these fissionable materials, particularly at high levels and furthermore no background exists to guide us as to which type of experiments ought to be carried on to determine the feasibility of these materials.

Representative HOLIFIELD. You mean you don't have the knowledge and at this time you see no way of getting it?

Dr. LUSTMAN. We are getting the knowledge in the course of this development, but there is no background of metal physics or solid-state physics such as exists in other fields which gives you a lead or which tells you some things can be ignored, but other things have to be investigated more closely.

Representative HOLIFIELD. It is not a matter of making experiments along the lines that you already know. You have got to find out how to make the experiments.

Dr. LUSTMAN. How to make the experiments and what are the right experiments to make. Certainly we have made a lot of wrong experiments. We know that.

Another factor here is the very restricted amount of space which is available in reactors for doing this sort of testing, the difficulty of performing power tests in these very high radiation fields which exist in test reactors and the limitations which the very high radioactivity of the test space means after they are discharged from the reactor, the limitations of the type of examination which you can perform on these materials. All of these factors limit the rate of progress in this field.

Representative HOLIFIELD. You spoke of trouble in making the tests afterward. Is that because of the fact you have to handle them remotely?

Dr. LUSTMAN. We have to handle them remotely behind 6-foot concrete walls. You are restricted to just the simplest types of examination—things which we wouldn't even think of doing if we could phyically handle the samples ourselves.

Chairman DURHAM. Where do you do most of your metallurgical testing?

Dr. LUSTMAN. The in-power testing is done in the materials-testing reactor. A small amount is done at Hanford. Some is also done in the Canadian pile at Chalk Rover.

Chairman DURHAM. That has to be done off the base here?

Dr. LUSTMAN. That is all done off the base. Examination after they are returned from a reactor is done here at Bettis in general.

Another factor is that as the design life of advanced reactor cores is continually increased and the amounts that burn up of the fuel are increased, you get into problems at these high burn-up levels which are not in the low burn-up levels, or relatively negligible at least at the low burn-up level.

Chairman DURHAM. Which would you classify as your greater problem at the present time: control of radiation or the heat problem?

Dr. LUSTMAN. From the point of view of materials, I think the most serious problem is the effect of irradiation on the stability of the material.

Chairman DURHAM. Created by heat—would that be true?

Dr. LUSTMAN. Partly by heat, but primarily by specific effects of radiation which we do not understand at the present time.

In the course of the evaluation of the PWR fuel element, for example, almost 100 sample fuel elements were exposed in a reactor and examined after their discharge from the reactor. It would be anticipated that at least as many in-power experiments would be required for the large ship reactor and probably more to fully evaluate or to get the same stage of evaluation as we did in the PWR. Even in the PWR we simply do not have all the problems evaluated which we are sure we are going to meet in reactor operation. It is only by the operation of a reactor core that you really can evaluate the use of a new type.

Decisions have to be continually made to bypass or shortcut some sort of experiment and these decisions have to be made between Bettis and NRB technical personnel again. So we don't expect that we have made all the correct decisions.

Representative HOLIFIELD. In other words, like true scientists you would just keep on making experiments to find out more about it if you weren't stopped by the one that said we have got to get on with the job and use what we have got.

Dr. LUSTMAN. We have to say at some point, "This is far enough."

Admiral RICKOVER. We have never fixed on a reactor design yet where we had all the information we really needed. Every reactor we have built in our program has taken a calculated risk. We are doing it every day. We just don't know enough and if we waited until we got enough information we would probably never build a reactor.

Dr. LUSTMAN. As I said, we certainly don't think we have made all of the right decisions.

I think the final important area of development here at Bettis which I will just briefly mention are the development problems which arise during the course of building and assembling a reactor core.

A large number of important, unspectacular developments are necessary to make sure that the fuel elements and assemblies are fabricated under actual production conditions to tolerance levels and qualitative levels to assure efficient core performance.

Representative PRICE. Thank you very much, Dr. Lustman. Are there any questions?

Representative HOLIFIELD. I am in somewhat the position of Dr. Lustman. I don't know just exactly what question to ask.

Chairman DURHAM. The problem is no different from all the basic research in past history.

Dr. LUSTMAN. That is right. There is no physical way whereby we can reproduce these effects in fuel materials. There is no way we can simulate these effects. We have to put these things into reactors.

Representative HOLIFIELD. Are you using the Hanford reactor?

Dr. LUSTMAN. Primarily the MTR and NRX reactor at Chalf River.

Representative PRICE. What part has Bettis played in the development of zirconium?

Dr. LUSTMAN. Bettis developed the alloys which are presently being used and developed the fabrication technology. Reduction technology was developed by the Bureau of Mines primarily.

Mr. SIMPSON. Zircaloy 2, which is commonly used, was developed at Bettis. The reduction of that to being able to melt and fabricate and weld and use it in a reactor was developed here at Bettis. The creation of the materials from which to start was done by the Bureau of Mines basically. Of course, Bettis, Argonne, Battelle, and many others participated.

Chairman DURHAM. In the fabrication is there much difference in the work involved between the two?

Dr. LUSTMAN. Surprisingly enough, not very much. I think the fact that when you fabricate a metal you are able to fabricate in terms of large ingots whereas oxide is fabricated in terms of small pellets, causes a higher price for the latter type of procedure. The differences in cost are not that striking. As development continues there will be relatively small differences in price between these materials.

Representative PRICE. Thank you very much, Dr. Lustman.

Mr. SIMPSON. Mr. Chairman, in my discussion I referred to the problems of components design, components development and the materials development other than the core materials and the fuel materials.

I would like to ask the manager of the SFR, that is the submarine fleet reactor, Mr. Squire, if he would say a few words on that.

STATEMENT OF ALEXANDER SQUIRE, MANAGER, SUBMARINE FLEET REACTOR, WESTINGHOUSE ELECTRIC CORP.

Mr. SQUIRE. Mr. Chairman and gentlemen, I would like to combine two things in my discussion. One is the development of the design of the reactor plant. The second one is the specific problems on what one might call nonnuclear components. By nonnuclear components, I mean such things as the steam generator, a model of which I have over here and to which I will refer later. Mr. Simpson mentioned the basic concept of maximum reliability of components. For a reactor plant, particularly for a naval reactor plant such as the SFR, we are continually mindful of the consequences of failure of even the smallest component in a submarine plant. Since a submarine must operate submerged or maneuver in time of war we do everything in our power to develop components, to design and to manufacture components that have the maximum degree of reliability. At the same time it is necessary, as Admiral Rickover has emphasized, to utilize the available weight and space at our disposal to the maximum degree.

There is a third item of which we are cognizant as we develop new plants such as the submarine fleet reactor plants. That is, we are conscious of the fact that the Idaho plant and the *Nautilus* plant are the first of a type. That has been discussed to a certain extent here and I think it should be reemphasized that we recognize that is the model of the nuclear powerplant industry.

It would be relatively simple for us to duplicate the *Nautilus* plant for these later submarine powerplants. We think that would be wrong because we feel we can only develop knowledge by taking a fresh look at these plants and doing everything we can to develop new

concepts. When a desire for additional submarine nuclear powerplants was expressed, we got together with the naval reactors people and the Pittsburgh area office people and we attempted to set ourselves objectives to be gained. Objectives that we had not met in the *Nautilus* plant or in the Idaho plant, but which we believe to be desirable.

Some of these objectives were: better use of weight and space at our disposal; improved access to components in case they should fail or in case they should require maintenance in service; improved ability to service the components once we had got to them.

Representative HOLIFIELD. You are not talking about shifting to sodium?

Mr. SQUIRE. No sir, we are talking strictly about water-cooled plants and attempting to improve on that foundation. Our activities have been restricted to the water-cooled plants so far.

So we got together with the technical people from the Naval Reactors Branch and with their knowledge of naval requirements set ourselves a number of objectives for submarine plants—the submarine fleet reactor plants which I am using only for illustration purposes.

As we attempted to develop our ideas we constructed models of possible plants in addition to the paper studies of these plants. One of the reactor plants incorporated a steam generator of the type I am showing you—this model standing here in this room. The steam generator is, of course, the main vehicle for transferring heat from the reactor plant to what we call the secondary plant, the turbine plant. This new steam generator offered real promise for improved space utilization. However, a steam generator of this type to perform in accordance with our operational requirements had not been built before.

The Naval Reactors Branch people and we, jointly, went to the manufacturers of components of this type and discussed with them the feasibility of the manufacture of the steam generator.

Representative HOLIFIELD. You are talking about changing from the *Nautilus* type to an improved type?

Mr. SQUIRE. Yes, using in general the same principle. The manufacturers of equipment of this sort saw no reason why such a unit could not be built. We decided it was worth a trial. It had not been done before, but it was worth trying out for the possible gains to be made in advancing the design of reactor plants.

Representative HOLIFIELD. How does the model compare in size?

Mr. SQUIRE. This, sir, is one-quarter of the size. That is for this particular plant. A plant of larger capacity, obviously, would require a larger steam generator.

As I said, we decided to go ahead and make this. To make a long story short, we had to make dozens of forgings before we could get forgings of adequate quality to put in these units.

There is an obvious question as to why we had so much difficulty getting these forgings when people have been making large forgings for many years. This brings us to another basic point in component design and construction. In naval powerplants or in any reactor plant, for that matter, one of our requirements is that we be able to heat up and cool down these plants rapidly. The obvious reason for this is that it may be necessary for these plants to get up a head of steam and get out of a given port or a given location on very short notice.

In order to minimize the problems associated with rapid heatup and in order to minimize the thermal stresses that are set up in components like this, it is necessary to use as thin sections as is consistent with reliability of the components. In order to use the thinnest sections possible, we have got to get the soundest material possible. We did not set ourselves goals that people believed were unattainable, but we set ourselves goals that we believed we could meet, but not very easily.

We finally obtained enough forgings to take care of this program, but in so doing actually the forging technology had to be advanced. Melting practices had to be improved by the forging suppliers and so one might say that there has been a broad gain by standards set up at Bethlehem and Midvale Co., just in building these units.

Chairman DURHAM. What did they do to it?

Mr. SQUIRE. It was more a question of controlling the melting practice more closely, limiting the time that the material was kept at temperature, controlling the additions that they used for the refinement of the grains in the material, and controlling the forging processes more closely than they normally do. There has been no basic change in composition.

Chairman DURHAM. No change in composition of the alloy?

Mr. SQUIRE. No basic change in composition of the alloy although at one stage in the game, the companies threw up their hands.

Admiral RICKOVER. Mr. Durham, on surface ships with which you are familiar, like the one you were on during World War I, we get one-tenth of 1 percent of sea water through our condensers in what we consider a normally tight condenser. With our boiler water compounds we can blow down and get rid of it. With stainless steel you can't do that. With stainless steel, if you get a few parts per million—it is just fantastically small amounts that will cause cracking in tubes.

As Mr. Squire said, since the whole source of your water—all your fresh water on naval vessels comes originally from salt water, it is very difficult to keep minute traces out and yet it is the minute traces that concern us and cause failure. We do get around it by having suitable boiler water treatment and renewing water frequently.

Mr. SQUIRE. There are several ways of preventing failure of boiler tubes. One is complete removal of the chlorides and oxygen or any other chemical that might influence failure.

There has been a major effort put on this by all of the manufacturers of steam generators in this business. The Naval Reactors Branch have been working with the boiler manufacturers.

I just want to leave this thought with you before I terminate. All the problems are not associated with cores. There are many, many problems associated with the more common materials and actually these problems seem to hold us up just as much as such things as uranium.

Mr. SIMPSON. We have now covered the physics, the metallurgy as applied to cores, the materials as applied to the other components and a typical design problem of the nonnuclear components.

I would like now to ask Dr. Esselman if he would take a few minutes to describe the advanced development work which we are doing in reactor plant design concepts and in looking at some of the other possibilities than the plants which are actually built. Dr. Esselman spent 2 years out in Idaho in actual "rubbing shoulders" work with radioactivity. He was in charge of the technical operation of the naval reactor facility there. He has known radioactive contamination firsthand and also the maintenance problems. He heads up our development here with a real down-to-earth background of the practical aspects of reactor design and operation.

Representative PRICE. Dr. Esselman.

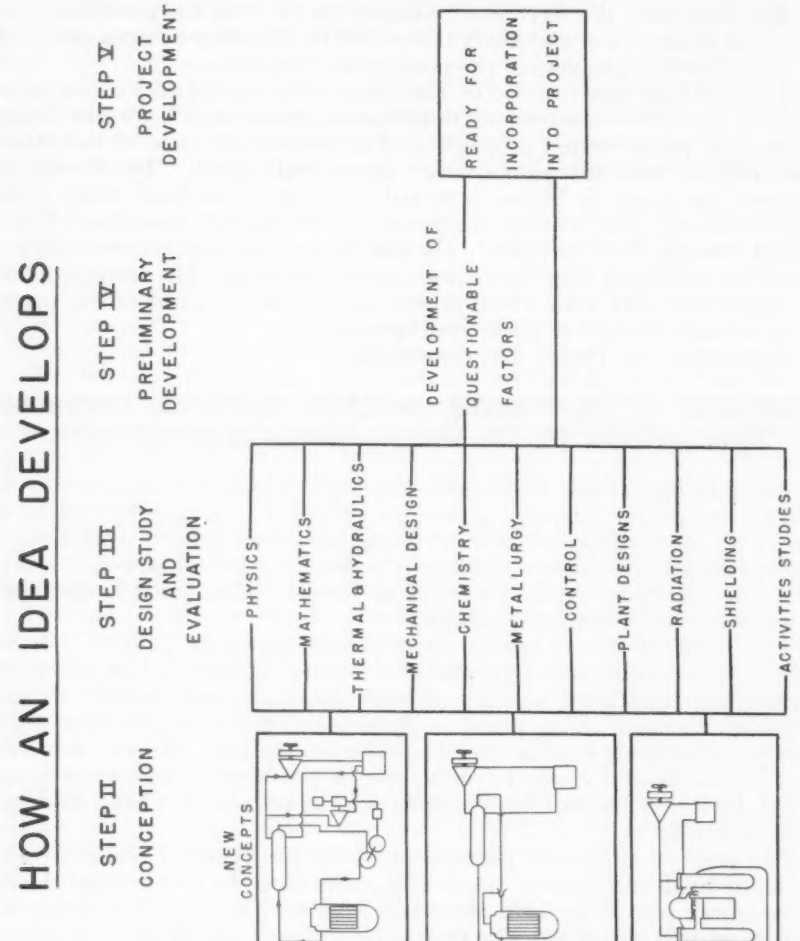
STATEMENT OF DR. WALTER ESSELMAN, MANAGER, ADVANCED DEVELOPMENT GROUP, WESTINGHOUSE ELECTRIC CORP.

Dr. ESSELMAN. Mr. Chairman, the topic which I wish to cover is the procedure for developing an idea before it is incorporated into a project. Many ideas are always being suggested and it is necessary for someone to determine whether it is feasible, desirable, and worthy of being incorporated in a project at Bettis. This work is done by the advanced development group.

The work of the advanced development group is primarily concerned with applications for naval reactors. However, the concepts which are considered worthy of consideration would apply to all types of reactors. This point is illustrated by the objectives of this group in that their studies are all based upon trying to achieve reduced cost of plants and cores, reduced weight per shaft horsepower and, third, maintenance and improvement of the reliability of the nuclear reactor plant.

The first of these—at reduced cost—naturally is of value to all types of nuclear reactors. Secondly, to reduce the weight per shaft horsepower also reflects in the plant cost and usually if a plant is lighter, it will cost less. The third one which is the reliability objective, I have stated as "maintaining reliability" because I do not wish to imply that we are not pleased with the reliability of the powerplants which we have built, but rather any new idea which we would conceive or evaluate should not jeopardize the record which has been made to date.

In order to illustrate the steps which are taken prior to the use of any idea, your attention is invited to this chart. This chart indicates how an idea is developed.



Step 1 is the need for basic information. Basic information is not much stimulus for coming up with new concepts and if you come up with a new concept, you have no information or data with which to evaluate. This information is obtained from other laboratories in the case of plants which are different types than we are building here.

The second one of our great sources for information is the naval reactor facility at Idaho. The third is various reports. The fourth that I have indicated are experiments at Bettis and the fifth is experience on the *Nautilus*.

In order to illustrate a typical example of where information is of great value, I would like to take the field of thermal hydraulics. During design stages on core No. 1, very little was known about the amount of heat that could be passed through a surface—metal surface without causing melt down. A laboratory was set up at Bettis to get experimental points under various values of waterflow, various values of temperature and today we believe we know quite accurately what the burnout points or melt-down points are on heat transfer surfaces. There are many other facets of hydraulic problems of which very little is known. Today we feel we have solved some of these problems. This field is very important in that the power output for any particular core is governed by the amount of heat we can pass through this surface.

We are continuing experiments in this thermal hydraulic laboratory in this field of transient heat flow. At the present time output on several of our cores is limited because of the transient that occurs if the pump would stop. To date no laboratory has done any experiment on transient heat transfer which we can apply to designs which we are making on water-cooled reactors.

The data that we obtain from the naval reactor facility is also important. In fact, it is the only power reactor that we have available to obtain information on reactor operation. At that facility we are continually checking on the activity buildup in loops and performing other chemistry tests. Experiments are being performed on core lifetimes. Unless you have a power facility you cannot really determine the practicality of these principles and you cannot really determine what the life of a core would be.

We are also doing experiments in heat transfer.

When we get this information the next step is the conception of new ideas. Actually the conception of new ideas is not a difficult part of this process. The difficult part is to evaluate the ideas that you have to determine which are good ones and which are to be followed. Many ideas are available for evaluation. The thing that is difficult is to limit the number of studies we want to make by this group to a number which can be accommodated with the few people that we have. At some time we combine several ideas or a number of ideas and discuss the possibility of starting a design study on a typical type of ship. We discuss with the AEC Naval Reactors Branch. We decide, for example, that the study should be conducted for a submarine or some other type of surface vessel.

We are making at this point a very practical study of a design concept. We are making a desirability study of a plant for a particular ship. The third step then is the design study and evaluation. The number of technologies that are involved are indicated. Actually there is probably only one of these various technologists performing this study so this is a relatively small organization. The more scientific aspects require the work of physicists, mathematicians, and metallurgists. The engineering aspects are covered by thermodynamicists and thermal hydraulic mechanical design, control engineering and you see here things such as plant designs. Actually in the study we will make an actual plant layout.

These studies are sometimes affected by things in the engine room which are quite remote from the actual reactor which we are design-

ing. Radiation studies are made in various plants and are compared based upon irradiation to the crew in this ship. If we were making a general study and were not confining this to a particular type vessel, the radiation problem would change, and this changes the concept of what we might build considerably.

At the end of this study we now have established that a particular concept is desirable. I hesitate to use the word "feasible" because at this point what we have come up with is a knowledge that a certain type plant would have a certain weight per shaft horsepower. It will have certain operational characteristics, but there are usually a number of problems that require development. The development of these is then undertaken on a small scale.

Step 4 can be undertaken on a small scale to determine whether some of these features that we consider problems really exist. Finally after we have done this it is ready for incorporation into a project. If we have enough knowledge of the plant which we are designing, for example, if it was a water-cooled plant, we would not have to do too much development in this step 4. It could go directly into a project.

I do not wish to indicate that the development is anywhere nearly completed at this point. It is really only beginning. What we have established to the point of incorporation in a project is that an idea will probably be feasible when the development in the project is completed. We have merely sifted the various ideas which were presented to those which are probably capable of solution and should be incorporated in a reactor plant.

Representative PRICE. May the committee have a copy of those charts for its record?

Dr. ESSELMAN. Certainly.

In conclusion I wish to state that we are looking at various types of reactors. The advanced development group's thoughts are quite broad in scope. We are looking at improvement to water-cooled reactors as well as other types of reactors. I think the setup which we have whereby the various people in the study group are so closely related to the people in the projects results in a very practical approach. The fact that the people in the study group realize that the ideas which they are trying to sell will very soon be in a project forces the practical approach. Also the people in the group are the ones who have had experience with the design of core 1 or the mark 1 plants or with the operation of a plant so that the personnel we have will certainly take the practical approach in any design study.

Representative PRICE. Thank you very much, Dr. Esselman, I see it is close to 1 o'clock. I think the committee should recess and if there is any further presentation we can return here this afternoon.

(Whereupon at 1 p. m. the subcommittee recessed.)

AFTERNOON SESSION

The Subcommittee on Research and Development resumed its meeting at 4 p. m. in conference room No. 2, Westinghouse Bettis plant, Pittsburgh, Pa., Hon. Melvin Price (chairman of the subcommittee) presiding.

Present were Representatives Carl T. Durham (chairman of the full committee), Chet Holifield, and Melvin Price (presiding).

Staff members present: James T. Ramey, executive director and George E. Brown, Jr.

Representatives of the Atomic Energy Commission: Kenneth E. Fields, General Manager; W. Kenneth Davis, Director, Division of Reactor Development; Rear Adm. H. G. Rickover, Chief, Naval Reactors Branch, and Comdr. V. A. Lascara, Naval Reactors Branch; John M. Bodley, Special Assistant to Commissioners Libby and Vance; Bryan F. LaPlante, Congressional Liaison Officer; L. D. Geiger, Manager, Pittsburgh Area Office, and Comdr. R. V. Laney, Assistant to Pittsburgh Area Manager (Reactors).

Representative PRICE. The subcommittee will be in order.

I think the committee may want to discuss some of the things that we saw here this morning and get the reactions to the presentations that were made this morning. We would also like to know from the local people here, representing the AEC, what they find their problems to be—matters of supply—matter of funds.

I think the members of the committee all agree with me that this is probably one of the most important projects to our national defense of any that we have in the AEC program. I think they would also agree with me that the AEC and Navy both should give it the fullest possible importance and do everything they possibly can do to promote this project and to expedite the various programs.

If someone would like to make a presenation on behalf of the Atomic Energy Commission, this committee would certainly be happy to have your presentation.

STATEMENT OF KENNETH E. FIELDS, GENERAL MANAGER; W. KENNETH DAVIS, DIRECTOR, DIVISION OF REACTOR DEVELOPMENT, AND ADM. H. G. RICKOVER, CHIEF, NAVAL REACTORS BRANCH, ATOMIC ENERGY COMMISSION

Mr. FIELDS. I didn't have any presentation to make from our side on this endeavor. I would definitely second what you have said so very strongly that this is one of the most important installations we have. I have been impressed with it ever since my first association with it in the sense that it is a clear illustration of what is necessary, I believe, in a number of areas in our reactor program—not just here, but elsewhere too. You have got to go all the way through a reactor program to come out with effective reactors. You can't just build the end product. There is a great deal of research and development in material, physics, and metallurgy that must be done. From what I have been able to make out you can do everything with respect to reactors here that needs to be done with one exception. That is the chemical reprocessing of fuels. You don't attack that problem here. Otherwise it is a complete system, as far as I can see, in propulsion plant development.

Chairman DURHAM. Is this the only place that we have where we can build a reactor from the ground up?

Mr. FIELDS. Knolls can do this and I would think——

Mr. DAVIS. Argonne.

Mr. FIELDS. Argonne and Oak Ridge not quite to that extent, but they are building reactors or getting to it. They haven't built them as big as the PWR.

Chairman DURHAM. I am talking about something of the size of the PWR.

Mr. FIELDS. I think it is a very complete research and development installation in that it has the scientific resources and research sort of efforts that go on here and are necessary to develop a particular concept of reactor. Here the work you are doing in the pressurized water reactors will be used very widely in the naval field, but it will also be extremely useful in a civilian power field. You have the general key coming from this. I believe parts of the Consolidated Edison central station reactor very definitely flow from this.

As far as I know we have given this every help that it needs as well as encouragement. We are very strongly of the belief that there is a great future for this kind of a reactor both for naval use and for civilian power use. Although it is useful in naval propulsion it is the same information you have to have for civilian power reactors. This material you have out here would behave the same whether it is a military reactor or a civilian reactor. So there are great benefits to a civilian program that will flow from the military research that is being done. There has been a great deal of declassification that has opened up much of this information to the civilian program.

Representative PRICE. How extensively is this project declassified?

Mr. FIELDS. You had better answer that, Admiral Rickover. I am under the impression that practically everything on the PWR is now declassified.

Admiral RICKOVER. The PWR is completely declassified. We have actually gone much further than that. We have taken practically all the technical information from the naval programs and have declassified it also. We have set up a distinction between the technology as such, as opposed to specific design and dimensional characteristics. We have decided and the Commission has backed us that pure technology shall be declassified. We have made that unclassified information so that anybody in this country who wants to build a pressurized water reactor can get all of the technology. As far as giving our specific dimensions for a submarine reactor, we are keeping that classified.

Representative HOLIFIELD. What about specific cores for the PWR and all of these—your techniques for making these fuel rods?

Admiral RICKOVER. Let me put it this way. There is not a single thing in the PWR which is now classified. I don't know of a single aspect of the PWR, whether it is technology or whether it is design, or construction or dimensions that is any longer classified.

There are sometimes arguments as to whether new reactor ideas should be made public. You know the theory in the reactor game that everything that is born is always born with a restricted data stamp on it. We are pretty much disregarding that with the new PWR cores that we are developing. I am sure your committee would want it that way. We feel that for civilian reactors there is no reason why we should go back to the old system where scientists and engineers could not talk with each other. We think it is of much greater advantage to the United States to get this information out into the people's hands. I am talking now as a military man. I think it would hurt this country not to do it.

Chairman DURHAM. Does that include all metallurgy also?

Admiral RICKOVER. It is all-inclusive for the PWR, Mr. Durham. It includes the technology, the physics, the fabrication techniques—anything at all. There is nothing in the PWR we classify. It is just the same as if you were going to buy a toaster, a phonograph, or something like that.

Mr. FIELDS. I would like to footnote a couple of things that occurred to me while we were listening to these presentations and in going through here today.

At some point in the briefing there was a discussion of the second submarine core. I am not sure it was the second core actually. It was a subsequent core where we developed a longer life and the fact that the idea for this concept came in 1952. I believe that was the date the man gave. Here it is 5 years later. It was first thought of 5 years ago. Let me just put that one fact down. In the second one they brought out these different materials.

The reason I wanted to sort of footnote these is because these are the successes in development and achievements that let this go forward, but they are really only the first steps. There is a long way down the road to go yet even in this particular area. I believe we make the mistake too often when we have gone through and developed something like the PWR of thinking that is the end of the road when it is really only the first step for the pressurized water reactor. There are any number of years when this same group here should continue this development of new types of cores and modifications of the PWR itself to improve the power levels and the performance of that particular reactor. That is the way you are really going to go forward in this business.

Representative HOLIFIELD. I am glad you brought that up. First let me ask you when the PWR will be finished? That is in the fall, isn't it?

Mr. FIELDS. The last I heard is late in the year.

Admiral RICKOVER. We have hopes that it will go critical late this year. It may not be this year and it may not be until some time early next year. We don't know. We are trying to get a reading on it.

There are two principles we follow. One is that under no circumstances should we go ahead and make an announcement about something here, advertise it and not have it come through. Second, I don't think we should do anything—take any shortcuts which would jeopardize the successful operation. We have a large amount of instrumentation in this core which you don't need in an ordinary reactor. We are doing it for one reason, because we conceive it was the intent of the Atomic Energy Commission and the Congress for us to learn design lessons for future reactors from this core. That is one of the most important things. We don't want to take any shortcuts which will stop us from learning. The job is so much vaster than any of us originally thought. We all fell down on the time estimate. So it may take a litle longer than we originally thought.

I think you are finding this is true of all reactor programs. I think you have to realize that we are just today beginning to get a glimmer of what a vast and difficult thing a power reactor is to design and build.

Representative PRICE. How much of the physical part of the reactor is manufactured outside of your own installation?

Admiral RICKOVER. About the only thing we have made here is the core. That is our policy. Make the first core of its type in the laboratory because it is developmental. Practically everything else is made outside and nearly all on competitive bidding.

Representative PRICE. Have any cores been made outside? I am not talking about power reactors.

Admiral RICKOVER. May I answer that question in a different way? Let me rephrase your question if you will permit me to do so. What we have done is to establish an industry to make parts both for the naval reactor program and the PWR. Can I answer it that way because I think it will bring it out better?

When we strted out, of course, we had only one core for the Mark 1, but we realized if we were going to have a nuclear Navy, we would have to build up a nuclear industry. An industry for nuclear power consists of two parts. First you have to get certain raw materials. The basic raw material is uranium. That is supplied to us by the AEC so we dont' have that to worry about. The next thing is material such as zirconium. When we started out we made it at Government laboratories such as the Bureau of Mines Laboratory at Albany, Oreg., and by Government subsidization of Foote Mineral Co. and the Carborundum Co.

Then about a year and a half ago we went out and made contracts with three large companies for zirconium. This was all on a competitive basis, lump sum. One of the contracts was with the Carborundum Co. which was already in the business. Another company, National Distillers, is setting up a plant. The National Research Corp. is also building a zirconium plant.

We made contracts with these companies with funds supplied from Navy shipbuilding appropriations to get about 2 million pounds of zirconium a year for 5 years. At the end of that time it will be a completely open competitive market. These companies will put in enough additional capacity to take care of civilian reactor requirements also.

I would like to say that with the steps we have taken zirconium will be in open supply by a competitive industry.

Mr. FIELDS. Do you have any figures you could quote with respect to price before and after?

Admiral RICKOVER. I will give you some figures. When we started several years ago we were paying $300 a pound for zirconium sponge. That was the price when we first started. Next we made a contract with the Foote Mineral Co. What did that run to?

Commander LASCARA. It cost us about $250 a pound and we furnished the feed material.

Admiral RICKOVER. Mind you, that was the first contract.

Representative PRICE. With what company?

Admiral RICKOVER. The Foote Mineral Co. near Philadelphia. I think the total contract was about $2.5 million.

The next contract we made was with the Carborundum Co. for quantities which totaled up to about 30,000 pounds a month and we got that for about $13.20 a pound for sponge, roughly. So we have gone down from $300 to $250 to $13.20 a pound. The contract which we made this past year with Carborundum was for $7.72 a pound instead of $13.20 and the other contracts were even lower.

Mr. FIELDS. How long a term contract?

Admiral RICKOVER. These are 5-year contracts. These contracts are to the great advantage of the Government.

Representative PRICE. How much zirconium is being produced a year?

Admiral RICKOVER. We will get roughly out of all of these contracts about 2 million pounds a year, which we will need for the naval program and for PWR cores.

Representative PRICE. What is the potential demand for zirconium in the future?

Admiral RICKOVER. We figure with the expanded capacity that these people are putting in they will be able to take care of General Electric Co. and Babcock & Wilcox and others who are building commercial reactors. They are putting in additional capacity. This is a new industry, but it should follow the path of other industry. We feel the Government can get out of the zirconium business at the end of the 5-year period and buy it on a normal, competitive basis.

However, the General Accounting Office has just come up with the thought the Commission should not contract for raw materials in this manner.

Representative HOLIFIELD. I was going to ask if the other contract was a Navy or a commission contract.

Admiral RICKOVER. The Navy transferred funds to the AEC. The Commission handled it because all of the know-how for handling this material is in the Commission so we were faced with the proposition of setting up another Government agency——

Mr. FIELDS. There was another reason for procuring zirconium and beryllium in this way. We didn't see why we should have separate agencies trying to develop this industry.

Representative HOLIFIELD. I heartily agree with you.

Mr. FIELDS. We all agreed one agency should do it and I think it came out we felt we should do it and they agreed with us.

Admiral RICKOVER. Under no circumstances should any other Government agency get into this field as long as it is being handled properly and efficiently by the AEC. It so happens that the Commission has designated Mr. Geiger, the manager of the Pittsburgh area office, to handle all zirconium procurement. We deal through this one source and in this way we are able to get an advantage in price.

There is another major advantage. Most of the technical know-how on zirconium is located right in this Bettis plant. We have the people here who are qualified to instruct all of the new people how to do it and to do it efficiently and properly.

The Commission may need the help of Congress in connection with our present method of zirconium procurement.

Mr. FIELDS. What kind of an obligation do we have to make against that contract?

Mr. DAVIS. The terms of our contract?

Mr. FIELDS. In terms of contract you obligate money—do you obligate it so that if we cancel a contract, we give them some kind of cancellation determination?

Admiral RICKOVER. Commander Lascara, you are familiar with the details of that.

Commander LASCARA. The Navy has put up $7.5 million for cancellation charges for its share of the zirconium production over a 5-year period. I think the AEC has about $1.6 million in cancella-

tion charges for its share. During the 5-year period, if the contracts are canceled, say, at the end of the first year of the contract we are obligated to pay these companies a fixed amount for cancellation. I don't know what the exact dollar amount of the cancellation charge is.

Mr. GEIGER. The contracts are written so that if the Government were to cancel them before they start production or during the year or year and a half required to build the plant and get into production, we have certain obligations to pay up to a portion of their capital investment.

Chairman DURHAM. Up to 5 years?

Mr. GEIGER. No, sir; this is until the time they begin production. From the time they actually begin production, there are smaller cancellation charges. They are relatively small.

Mr. FIELDS. Going down to zero.

Mr. GEIGER. By the end of the 5-year period, of course, it is zero.

Representative PRICE. How many companies are in this business?

Commander LASCARA. There are three long-term contracts. We have a fourth company which has a short term contract.

Mr. GEIGER. Carborundum Co., National Distillers Corp., National Research Metals.

Admiral RICKOVER. National Research Corp.

Mr. GEIGER. NRC Metals is a wholly owned subsidiary of National Research Corp.

Mr. DAVIS. Only half.

Mr. GEIGER. Fifty percent of it was recently purchased by Columbia Southern, a subsidiary of Pittsburgh Plate Glass.

Representative PRICE. What is the fourth?

Admiral RICKOVER. Wah Chang. They are running the Bureau of Mines zirconium plant at Albany, Oreg. They have a lot to do with titanium. They have leased the Bureau of Mines—the Government-owned plant at Albany, Oreg. and are making zirconium for us now.

At any rate I would like to assure you that we have gotten a much better price, this way of doing it, for the Government than we could have done any other way. I hope the joint congressional committee backs this idea of doing it in this manner.

Chairman DURHAM. Is Wah Chang operating offshore of the continental United States?

Mr. GEIGER. No; Wah Chang is a domestic company.

Chairman DURHAM. He is all over the world.

Mr. GEIGER. It is an American company.

Chairman DURHAM. An American-Chinese company. He is the man who got a lot of tungsten out of China for us during the war.

Mr. GEIGER. He has brought in many minerals from many countries.

Chairman DURHAM. He is down in Brazil at the present time. Can you give us the contract price for each company?

Admiral RICKOVER. We can supply it for the record.

(The information referred to follows:)

National Distillers, $4.53 per pound; NRC Metals, $6.50 per pound; Carborundum Metals (Akron, Ohio), $11.42 per pound; Carborundum Metals (Parkersburg, W. Va.), $7.72 per pound; Wah Chang, $9.07 per pound (Government-owned facilities).

Chairman DURHAM. You mentioned a price of $13.

Mr. GEIGER. I can give you the price.

Chairman DURHAM. How long does that contract run at $13?

Mr. GEIGER. That original Carborundum contract runs until December 1958. Since they started production we have negotiated 3 annual price redeterminations bringing the price down to where, today, we are paying $11.42 a pound.

Chairman DURHAM. There is a renegotiation clause?

Mr. GEIGER. We renegotiate a new price once a year prospectively under that contract.

Representative PRICE. Do all of these contracts have renegotiation clauses?

Mr. GEIGER. The new contracts were all competitively bid contracts.

Representative PRICE. What was the lowest bid that you had?

Mr. GEIGER. The lowest bid is the one submitted by National Distillers of $4.53 a pound.

Representative PRICE. How many pounds do they supply?

Mr. GEIGER. A million pounds a year.

Mr. RAMEY. That is your largest contract.

Mr. GEIGER. That is the largest contract.

Chairman DURHAM. Are they producing?

Mr. GEIGER. No; they are not yet in production. They are building a plant at Ashtabula, Ohio. They were scheduled to be in production July of this year, but they are going to be late.

Chairman DURHAM. Where did they get their experience?

Mr. GEIGER. Several years ago National Distillers decided to diversify into the chemical field, and they set up a chemistry division. They are in the petrochemical field and they are also large producers of sodium metal. It was their interest in sodium metal which led them into the titanium and zirconium fields.

Chairman DURHAM. What was Wah Chang's bid? Do you remember?

Mr. GEIGER. Wah Chang is producing zirconium in a Government-owned plant. They are operating a Government-owned plant and selling zirconium to us for $9.13 a pound.

Representative PRICE. What makes the big difference in the prices? Was there no experience to begin with? Is it because the earlier process was not quite as efficient?

Mr. GEIGER. The biggest single factor is the rate of production. Today we are paying $9.13 a pound for material produced in a Government-owned plant where there is no amortization. We are paying $11.42 a pound in a plant that can produce at a rate of 300,000 pounds a year. The lower prices are based on production rates in excess of a million pounds a year.

Mr. RAMEY. Is there no difference in processing?

Mr. GEIGER. There are improved processes, but I think the production rate has a lot to do with the prices. If the production rate goes up, the price goes down.

Representative HOLIFIELD. I think we have got off the track a bit from our first line of questioning, although I am very much interested in this. I had asked a question as to when we would be through with the PWR. The reason I asked that question was because I wanted to see what kind of a breakdown your organization, Admiral Rickover, has in naval work that they are doing on the submarines and the work that they are doing on the PWR. Are you doing work on both of those projects?

Admiral RICKOVER. Yes.

Representative HOLIFIELD. You gave us some figures once before on the number of people you have in your organization. How much of that organization is devoted to the PWR and how much is devoted to the naval portion? Can you differentiate?

Admiral RICKOVER. I will try to give you some rough figures. Of course most of the developmental work in the PWR is finished. It has been for some time in the construction stage. Today the great majority of the work is in the followup of components and seeing that the installation gets done. I would say that about 20 to 25 percent of the effort of my organization is now devoted to the PWR. However, you must bear in mind that the technology in the PWR and the things that we do—what we learn on one reactor, we are learning for the others. That, of course, is the great advantage for having done the PWR here at Bettis and one of the reasons why the Commission assigned it here because it uses the same technology at the naval plant. For instance, a great deal we have learned on the PWR we are incorporating in the large ship reactor project. A great deal that we learned in naval reactors we have incorporated in the PWR. So even though we may spend 25 percent of our effort on it, on the other hand if we weren't doing it on the PWR, we would probably have to use about 12½ percent of the effort on naval cores anyway.

Representative HOLIFIELD. In the main you have put your best developmental people into the naval portion of the program?

Admiral RICKOVER. We use the same quality people on the naval program and on the PWR. We are starting a second core for the PWR. We have taken some of the developmental people, both here and in the Naval Reactors Branch, off the PWR and we are putting them on the other work because we no longer need as many on the new PWR core as we did on the original one.

Representative HOLIFIELD. As far as your organization is concerned, what will you be working in when you finish the PWR? You have a pretty good organization put together. Are you going to be able to absorb them in this big naval aircraft carrier and the submarine projects? Would you be able to take an additional project?

Admiral RICKOVER. You are saying, "When a man is already carrying a heavy load, could you add another straw before you break his back?" Sure, we could take on another project.

Representative HOLIFIELD. No, that isn't what I mean. If you have 25 percent of your people in the PWR, are you going to move them over into the naval program? Are you going to retain them or are they going to be dispersed throughout the country?

Admiral RICKOVER. No, they are not going to be dispersed. There is so much to be done that you can always find use for them. You were talking about another project. You asked me the last time I testified before your committee in Washington whether we could take another program. I said, "Yes," because I would just make out. I would train more people. You just keep on. That is all.

Representative HOLIFIELD. Do most of your finances now on the naval part of your program come from the AEC or does it come from the Navy?

Admiral RICKOVER. The finances are split two ways according to an agreement the Department of Defense made with the AEC. The research and development part is paid for by the AEC. The production part is paid for by the Navy. Any research and development on the steam part of the plant is paid for by the Navy, and construction of nuclear ships is paid for by the Navy. I think I can illustrate that better by giving you an example of how a big project works.

We will take the large ship reactor project. The AEC finances all of the research and development for the first plant. They also finance the construction of the prototype at Arco, and they finance the operation of the prototype. The Navy finances the entire cost of the ship plus the cost of the reactors in the ship. That is the general line of division between the AEC and the Navy. The AEC finances research and development plus prototype. The Navy pays for the ship and the cores that go into the ship.

Representative HOLIFIELD. Mr. Fields, how much are you using in the way of AEC funds to sustain this operation of Admiral Rickover's here?

Mr. FIELDS. I think you had better answer that, Rick.

Admiral RICKOVER. I will talk about fiscal year 1958. The AEC is putting up about $86 million for research and development.

Mr. FIELDS. $72 in fiscal 1957. That is operating funds.

Admiral RICKOVER. $86 million in fiscal year 1958. That does not include construction funds from the AEC.

Commander LASCARA. That is right.

Admiral RICKOVER. $25 million for construction funds—something like that. I don't know the exact amount.

Mr. RAMEY. How many people do you have?

Admiral RICKOVER. At Bettis we have about 5,300 people of whom about 1,300 are scientists and engineers.

Mr. FIELDS. This entire budget isn't spent here.

Admiral RICKOVER. It is spent here, at General Electric, Combustion Engineering, and many other places.

Chairman DURHAM. Does that $86 million mean completion of all the submarines that we have authorized so far?

Admiral RICKOVER. No, sir; that is not for actual construction of submarines. That is for research and development on naval nuclear propulsion—for the entire naval program.

Chairman DURHAM. I know that.

Admiral RICKOVER. You mean when we finish up with the $86 million?

Chairman DURHAM. Yes.

Admiral RICKOVER. No, sir. There will be continuous research and development in the coming years too.

Chairman DURHAM. In other words, you must expect research and development funds if you are not to continue building copies of the *Nautilus* type submarine reactor?

Admiral RICKOVER. We are not building any more *Nautilus* type.

Chairman DURHAM. I know. I am talking about whether you expect research and development funds from the AEC to continue the program on a research basis regardless of how many submarine reactors you build.

Admiral RICKOVER. Yes. If the Congress wants us to have improved reactors and wants us to learn, we have got to do this. This is the only way we know how to do it.

Representative PRICE. I want to get back to what Mr. Holifield started in his questions. Since the beginning of the Shippingport project which is when you are going through the peak years, what percentage of your work went into the project?

Admiral RICKOVER. You are talking about manpower?

Representative PRICE. Manpower and the efforts of your organization.

Admiral RICKOVER. At the peak it was at least 30 or 40 percent or perhaps more of this laboratory's efforts. I think it took about 300 scientists and engineers together with the necessary supporting personnel a total of about 5 years to do that job. That was a considerable effort. That same percentage applied in my headquarters organization in Washington. We actually gave the PWR the highest priority—even over the Navy program.

Representative PRICE. About 300 scientists and engineers during that period working exclusively on the PWR?

Admiral RICKOVER. That is right here at Bettis. This doesn't include people in the other organizations that contributed.

Representative PRICE. You are talking about the Bettis organization.

Admiral RICKOVER. That is about correct, isn't it?

Mr. GEIGER. I think that is right.

Representative HOLIFIELD. What are your general thoughts, Mr. Fields, for keeping this organization busy?

Mr. FIELDS. I don't think we have a problem in keeping them busy, Mr. Holifield. In a way this is the point I was trying to make. We have a tendency too often to think once one of these reactors go critical, that you have come to the end of the job, but you haven't at all. You have a tremendous payoff. Another 5 or 10 years in development at least—and probably more—in this field in extending the life of these machines, improving the cores, possibly modifications will come along in components, will simplify it, make it better.

Representative HOLIFIELD. How about starting from scratch and building on the basis of that knowledge—building another reactor? Is there a payoff there?

Mr. FIELDS. There could be, but——

Representative HOLIFIELD. In the meantime you keep on getting operating experience and you are improving.

Mr. FIELDS. You don't get operating experience by just operating a core longer than its life and replacing that same core in there. You need an improved type of core if you are going to progress down the line.

Admiral RICKOVER. Let me try to answer this question. I will give you an example.

Mr. FIELDS. O. K., but let me just say again that I think there is a tremendous amount of improvement possible in all of these things we have started. The PWR I would predict would be here for 15 years.

Admiral RICKOVER. Take the PWR. We will install the first core in it, and it will start operating toward the end of this year or the early part of next year. That core may last 3 or 4 years. In the

meantime we are designing another core. You might say, "Why don't we start and build another PWR reactor?" I wouldn't do that. I don't think there is enough gained.

Representative HOLIFIELD. That is what I am trying to get at.

Admiral RICKOVER. I wouldn't do that. I know this is contrary to what a lot of other people are saying. To go ahead and build a brand new pressurized water reactor and start from scratch will take 5 years at least, and the people who are going to design and build it are going to come around here and copy what they have here. So what have you got at the end of 5 years? You have got something that is already obsolete. As General Fields has said, we think it is much cheaper to design improved cores and use them in the present PWR plant.

Representative HOLIFIELD. Pull the old core out and put that in?

Admiral RICKOVER. When the first core is used up, install the second one; meanwhile start the design of a third new and improved type core. That would be the cheapest and best and quickest way of learning.

Mr. DAVIS. I think there is one more thing. It seems to me you have two problems in trying to develop something like the pressurized water reactor to the point where it is going to be pretty useful. One is to get the cost of the plant itself, which is very high in terms of dollars per kilowatt, down. The other is to get the cost of the fuel down. These are the two main components of the cost that are very high today.

You will do this in somewhat different ways. I think we have talked quite a bit about how we can cut the cost of a particular core and also extend its life. If you can do both of those rather successfully, you can cut the fuel costs into a fraction of what it is for the first core. You do this by putting in one core, then building an improved core and another improved core. You can put these all into the same reactor.

The cost of the reactor itself, I think, will come down largely after you have run the plant for a while and find out where it was that you were overly conservative when you designed it in the first place. I think you will discover, after you have run the PWR for a while and have perhaps put in 1 or 2 additional cores, that the water circulating system, the heat exchangers and the turbogenerators are, in fact, only perhaps a fraction as big as they should be to take the actual output of what you have out of the plant now that you know how to remove the bottlenecks. At that point somebody can come along and build a plant that, perhaps, wouldn't cost a great deal more than the PWR, but which will put out perhaps 2 or 3 times the output.

Admiral RICKOVER. It is too early now.

Mr. DAVIS. It is too early now and too early until you have run it and found out how to do these things. At that point you can build a plant which in capital cost—in terms of dollars per kilowatt—have become quite reasonable. At the same time you develop fuel cost where it is down to a point which is quite reasonable. At that point which, perhaps, is 3 or 4 years after you complete and operate your plant, you have a real sound basis for going ahead with a very much improved pressurized water reactor.

I think you have to take these things together and keep in mind that the things that bring down the cost in reactors are these two different

aspects. You have got to be able to do both of them. To do one of them alone is never going to make the grade.

Representative PRICE. How much is invested in the PWR right now?

Admiral RICKOVER. Investment in cost at the present time is $55 million for construction and about $40 million for research and development. This is exclusive of the cost of the steam plant, which is being borne by the Duquesne Light Co. I would say, roughly, the total expense of the PWR today is about $110 million.

Representative PRICE. Today.

Admiral RICKOVER. That is what we see will be the cost when it is finished about the end of the year. I am giving you overall cost.

Representative PRICE. By the time it is in operation?

Admiral RICKOVER. Yes sir. It looks today like roughly $110 million.

Representative PRICE. How much in excess of the original figure is that?

Admiral RICKOVER. I think Congress authorized originally $100 million for research and devolopment plus construction, which was $85 million for the reactor portion, so it is running over.

Mr. DAVIS. It was $85 million. You took out $15 million for the turbogenerator.

Admiral RICKOVER. About $100 million was the original estimate back in 1955. It has turned out to be about $110 million.

Representative PRICE. You have had these men working on this pressurized water reactor for about 5 years. I think they are probably among the best men in this field of reactors. Has any one of them ever expressed a desire to get into the business of building and testing gas-cooled reactors?

Admiral RICKOVER. Some of them have.

Representative HOLIFIELD. Do you need something in the way of a real challenge to keep these people now? Is there enough of a continuing challenge in improving the cores and other improvements on the PWR to keep your top people together or do they need something that would provide a real new challenge to them?

Admiral RICKOVER. I will put it this way. The people who are in this game, both in my organization in Washington and here, are not in it because of naval reactors alone. They are in this game in order to develop atomic energy in the United States. To them and to some extent this is true of me also, the naval program leads to this. So they would welcome a challenge of another type of reactor to work on. We have had discussions about this here at Bettis and in my organization and if the Commission decided to do this, we would be happy to take it on.

Certainly it would add more work for us, but we would make out. We would hire more people.

Representative HOLIFIELD. In other words, you could phase these people right into the program without damaging your large ship reactor.

Admiral RICKOVER. It always damages a little. We started out with one reactor, the mark 1, at Arco. Then as we undertook more reactor projects, we hired and trained more people. But all of the technology you learn on one type of reactor will add to another.

As I mentioned this morning, we are not starting off with novices. We are starting off with people who have, at least, a pretty good concept of what the design of a large scale reactor is. We would hope that we would have learned many lessons from what we have done in the past and not make all of the same mistakes.

Representative PRICE. Do any of them see any greater promise in a gas-cooled reactor than a pressurized water reactor?

Admiral RICKOVER. I think until you try out different types you can't say. I don't think you can hypothesize reactors. I think you have to try one of them out in order to find out.

Representative PRICE. Do they talk about the advantages of one over the other or what they think might be the advantage of one over the other?

Admiral RICKOVER. The major advantage of a gas-cooled reactor is that you can use natural uranium. If the policy of the country is to sell reactors abroad; if this is our national policy, you pretty much have to learn to design natural uranium reactors. Otherwise you force the countries to buy their fuel from this country if it is enriched uranium, or you force them to set up a uranium separation plant.

Representative HOLIFIELD. If you had the privilege of naming the type of reactor that you would like to go into, which one would you select?

Admiral RICKOVER. Gas cooled.

Representative HOLIFIELD. Gas rather than the homogeneous?

Admiral RICKOVER. Yes, sir.

Representative HOLIFIELD. Was the decision to go ahead with additional submarines in the pressurized-water field rather than in the sodium field based on the factor of sodium leakage?

Admiral RICKOVER. When we started out in the nuclear-submarine program we didn't know whether sodium was better than water, or vice versa. They both offered promise. As we went along—and before the *Sea Wolf* was finished—we recognized that water was better. By this time we had a water plant operating, so we then made the decision that for additional submarines we would go to water. We did that long before the *Sea Wolf* was operating, because we saw already that water was better than sodium for naval plants. However, we figured that we should go on and finish the job and try it out. We had to find out, and the only way you really find out is to operate the plant under service conditions.

The *Sea Wolf* is operating right now, and will keep on operating. If she develops another leak, we will have to take a look and see how expensive it is to repair. If it is too expensive, we may not continue operation. We are making plans now to replace the sodium reactor of the *Sea Wolf* with a pressurized-water type similar to the one that we have in the *Nautilus*.

Chairman DURHAM. Would there have to be any redesigning of the reactor to fit the *Sea Wolf*?

Admiral RICKOVER. We will use things we already have. There is plenty of room in the *Sea Wolf* to take a pressurized-water plant.

Representative PRICE. You are still running the *Sea Wolf* on shakedown?

Admiral RICKOVER. She is out operating right this minute. She will be at sea for about a month.

Mr. RAMEY. On the gas-cooled reactors, why can't we rely on the British for this information?

Admiral RICKOVER. It all depends on what philosophy you take on reactors. Normally, you can't learn the whole story from somebody else. You just cannot do it. You can get technical data, but if you really want to learn how to do something, you have got to do it yourself. Sure, you can get a lot of help from them, but you can't really learn unless you develop much of the technology in this country.

Chairman DURHAM. Why, then, are the British so anxious to get our information on these things?

Admiral RICKOVER. They are interested in water-cooled reactors, also. They want to get all the information they can so that, if it is necessary, they can try it out themselves. I did want to say a few more words about getting industry to do this job—which touched this off. I would like to talk for a couple of minutes on that.

Representative PRICE. Before you do that, could we get a list of the information on that project which has been disseminated to industry?

Admiral RICKOVER. Yes, sir; not only on the PWR, but the whole Navy program.

Representative PRICE. And also tell us how you get this out to industry?

Admiral RICKOVER. I will get something through the Commission on that to your committee.

(The information referred to follows:)

DECLASSIFICATION AND DISSEMINATION OF INFORMATION DEVELOPED IN THE NAVAL REACTORS AND PWR PROGRAMS

As of February 23, 1957, the following policy was established in the naval reactors and PWR programs:

(*a*) All information on the PWR plant at Shippingport is unclassified.

(*b*) All reactor technology developed on naval reactors is unclassified.

(*c*) All naval reactor design information is classified "confidential," "restricted data," or "defense information," as appropriate.

As a result of a document review conducted during March and April of this year at the Bettis plant, the Knolls Atomic Power Laboratory, and the Combustion Engineering Laboratory, over 5,000 classified naval reactor documents have been released for review and possible application to the AEC civilian application program. The information contained in these documents covers areas such as: reactor physics, reactor design, metallurgy, reactor plant components, and reactor control. To supplement this continuing document review, naval reactor laboratories will issue quarterly unclassified reports on the latest developments in reactor technology in these laboratories. These reports will be available to the public through the AEC's Technical Information Service at Oak Ridge, Tenn.

Representative HOLIFIELD. Is that released through the Commission?

Admiral RICKOVER. The Commission has set up a regular method of declassifying. What we are doing now is getting our laboratories to go over all of the information they have and put it in a form so it can be published.

Representative PRICE. Specifically, I meant the Shippingport project, but we would also like to have the information on other projects.

Admiral RICKOVER. I will give it to you for everything that we do.

Mr. FIELDS. May I say one thing at this point? On this question of adding another reactor project here, the Commission—I shouldn't speak for the Commission, but let me speak for myself at this point, which would be a recommendation, I suppose, to the Commission if we got to that point. I haven't seen anything the last year that I have

been around here to indicate that the people here are without work and don't have a lot to do and that there wouldn't be a serious problem if we were to confront this group with undertaking such a reactor as to just how much impact it would have on the naval program. I think there are two sides to this question, and I haven't seen any evidence that there isn't a lot to do here yet.

Chairman DURHAM. I would certainly have to be thoroughly convinced that it would in no way affect the Navy program before I would ever be for it. I think we face a serious challenge in submarines. After reviewing this program, there is no doubt in my mind that we are face to face with quite a vicious type of threat—not just a few weapons, but numbers and numbers of them.

Mr. FIELDS. Quite apart from the question of whether this country goes ahead with a gas-cooled reactor or not, there is the question of where it should go, and then another question is what you want to do.

Mr. DAVIS. I think it should be said that what we will get from the British on gas-cooled reactors is that we will find out what their economics are. We won't necessarily get the know-how with which to build one. I think it is important to recognize the difference between these two things, too.

Representative PRICE. What will we get, then, from the British?

Mr. DAVIS. We will certainly get enough information to evaluate the reactors with respect to what they can do. I don't think we will get enough so that we could, without doing quite a bit of development ourselves, actually build one similar to theirs or improve on it.

Representative PRICE. I thought there was some question about relying on British figures for the economics of their reactor.

Mr. DAVIS. I think what one has to do is to make his own figures, but base them on their costs. That is like trying to develop figures, for example, of what it would cost to build another PWR. You don't assume everything costs the same. You go through and make your own figures as to where it is going to be built and the conditions under which it is going to be built.

There is more to extrapolating the British reactor to United States figures than there is to extrapolating the PWR from here up to Rowe, Mass., for example. Nevertheless, I think it can be done and that there will be sufficient information to do this. However, if we gave somebody the job of manufacturing the fuel elements similar to the British fuel elements to put them into a gas-cooled reactor, there would be a lot of know-how which they would either have to go and get or they would have to learn by themselves. These, as I say, I think are related but still somewhat different considerations.

Chairman DURHAM. Do you have a proposal at the present time to build a gas-cooled reactor?

Mr. FIELDS. Aerojet.

Mr. DAVIS. We are going ahead with Aerojet. However, that is a very small, quite high temperature, closed-cycle, gas-turbine reactor.

Chairman DURHAM. Don't you have a regular power-producing reactor proposal before you of the gas-cooled type?

Mr. FIELDS. I believe Mr. Durham is referring to one under consideration by the Florida Power——

Mr. DAVIS. There is a Florida nuclear-power group.

Chairman DURHAM. At least you announced it several weeks ago.

Mr. DAVIS. We have had discussions with them. They have not

made a formal proposal to us yet. We have had a number of discussions. They are thinking about a heavy-water moderated reactor using natural uranium, either gas or heavy-water cooled. I think their proposal, when it finally comes in, will probably be, at least for the first year or so, to consider both gas cooled and heavy-water cooled and to make a selection later depending upon which looks the best. These would be quite different than the British reactors, which are graphite moderated. It would be more similar to what the Russians have said they are working on—gas-cooled, heavy-water moderated.

Representative HOLIFIELD. In computing the British costs, do you have any difficulty with respect to what allowances they are making for plutonium?

Mr. DAVIS. We have some ideas, but it depends so much on who has been doing the talking. I think in this case they haven't really decided yet.

Mr. FIELDS. We don't have any report that says, "This is the allowance we are making for it," if that is what you mean.

Mr. DAVIS. Actually with the Calder Hall reactor, you see, they are getting what they can for power, which is about 5 mills, which is what Central Electricity Authority will pay the Atomic Energy Authority for power. The plutonium will cost whatever it would have to cost to balance off the rest of the cost. With the Central Authority reactors, presumably they are going to do it the other way around. The Central Authority will sell the plutonium to the Atomic Energy Authority and they will try in their power cost to make up the difference. They are still trying to negotiate, as I understand it, to make things come out right but they haven't arrived at a final figure as far as I am able to find out. I don't know what the figure is.

Mr. FIELDS. I wonder if I could finish what I started to say.

Representative PRICE. Go ahead.

Mr. FIELDS. We started from the point that you have a rather complete research and development effort here in the field of water reactors. What concerns me, frankly, about the situation and the arguments that we have had between various groups on how to proceed with reactors is this: You look at this effort. It has been very expensive and it is going to be expensive for a good many years ahead if this is to be a strong effort here at this installation just in this area of water-cooled reactors. Similarly we have the effort at Argonne which is also in a water field, although this has been boiling-water reactors, and they are in breeding reactors and other aspects of the reactor field. We have a strong group at Oak Ridge in the homogeneous reactor field and in some other activities there. There are certain other groups like Los Alamos that are beginning to get into the plutonium type of reactor. These groups in themselves are going to be very expensive and have a yearly operating expense of anywhere from $20 million to $50 million per installation just to keep those going. They are going to be able to come up with fruitful developments for a long time to come. It is far more important, I think, to this country for those groups to stay strong and active and thoroughly engaged in their fields of endeavor which are in slightly different reactor-development areas, than it is to start building a certain number of new complete production plants or powerplants at any particular time.

Once in a while they will reach a certain stage where there should be some powerplants built. We are building powerplants—not necessarily big ones, but like the EBWR. However, I hope in the considerations ahead that we continue to support these main-line development efforts that are so important to the progress in the field. I think this concerns all of us who are sitting here as much as anything in the picture.

Admiral RICKOVER. I agree.

Mr. FIELDS. We admittedly should build some once in awhile.

Representative PRICE. If you don't build some once in awhile, you are not going to get any place. You are always going to have experimental projects.

Mr. FIELDS. It is a matter of judgment as to what kind you build. I agree there should be targets along the way. Maybe you set a target like the EBWR at Argonne at one stage and maybe next time it has to be as big as the Dresden reactor or something of that type.

Mr. DAVIS. Almost all reactor projects have reactor experiments.

Representative PRICE. You can't keep them in the experimental stage forever. You have got to advance.

Mr. DAVIS. What has happened here is that, for example, the boiling water reactor is being followed by the G. E. small boiling water reactor and about a year later will be followed by the full scale boiling-water reactor which is being built for Commonwealth. If this kind of development is picked up at the proper stage after reactor experiment, then I think you have got a very logical sequence of development of these reactor types. If you get one that is developed and looks like it is a really good idea and somebody ought to do it and nobody does it, eventually you have got a problem. I think this is the way, if it works, that it will probably work the best—at least to my mind.

Mr. RAMEY. However, Argonne is building your water technology—your boiling water—and they are doing the breeder type which are dissimilar types of reactors.

Mr. DAVIS. Very dissimilar.

Mr. RAMEY. North American has a sodium graphite program and is doing an organic moderated job, so you do have, shall we say, a precedent for other installations doing two different types of reactors. I think one question then is why couldn't Bettis do two different types of reactors? Why couldn't Bettis do the pressurized water and the gas-cooled? Granted that they would start out on a small one probably——

Mr. DAVIS. These other installations are not doing military projects at the same time.

Mr. RAMEY. Argonne started off on the naval reactor program as well as civilian reactors.

Mr. DAVIS. Oak Ridge is an installation where we have got one main civilian power reactor effort and one main military reactor effort; that is true.

Mr. FIELDS. It is possible certainly. It hasn't happened.

Representative PRICE. I think Admiral Rickover was about to make a statement. We yield the floor.

Admiral RICKOVER. I wanted to add a few words about what we are doing in getting industry into this picture. We are in the process of establishing heat-exchanger manufacturers, valve manufacturers,

pressure-vessel manufacturers—all on a competitive basis. Although they started with a naval project, these same organizations are capable of doing this work for civilian projects.

The last time I testified I mentioned that even for our naval program 86 percent of our money being spent for procurement, is being spent competitively and on competitive bids. This includes reactor cores, valves, instrumentation, and so forth. That is the thing I wanted to touch on for a couple of minutes. We now have Olin-Matheson, Combustion Engineering, Westinghouse Electric, Babcock & Wilcox, and Metals & Control Corp., at Attleboro, Mass., all engaged in building naval reactor cores. As these people get experience they will be available to make cores for anybody. We will soon have more than one company capable of bidding competitively for most of the items that go to make up a nuclear plant. We are also doing this with respect to zirconium on the same basis that the AEC handles zirconium procurement. The AEC is purchasing reactor cores for the Navy, but the Navy pays for them by transfer of funds.

Unless we do it this way we are going to be faced with the problem of duplicate facilities being set up by the Navy. Since cores are still in the developmental stage, I think that would be wrong. I think it ought to be under one Government agency so that we do not duplicate purchasing organizations, inspection groups, and so on. In this way it will be most economical for the Government.

I think it is very important that we not divert our efforts and have, for instance, the Air Force start getting people to make cores and the Navy start getting people to make cores. This early in the development stage, I think it is extremely important that one agency, the AEC, have charge of it.

Representative HOLIFIELD. I certainly agree with that.

Chairman DURHAM. I felt like that on reactors all the way through.

Admiral RICKOVER. There is one more think I must say which I have said many times before, but I would like to say it again. Had it not been for the Atomic Energy Commission and the Joint Congressional Committee we would not have any nuclear-powered naval vessel today. I think these two organizations and their way of operating deserve most of the credit.

Representative PRICE. Are there any further questions?

Chairman DURHAM. Do you have enough funds to carry out your work this year?

Admiral RICKOVER. No sir, no one ever does. You ought to know that, Mr. Durham, as many years as you have been in Congress. You ask a question like that. It is surprising.

I would like to answer your question though, Mr. Durham. The AEC has given me all the money that I have asked for in the naval program. The program is advancing rapidly, however. We can use more money.

Chairman DURHAM. Has the Navy given you any?

Admiral RICKOVER. The Navy hasn't given me as much as I have asked for. But Admiral Burke has stated that he would make more money available next year to carry out the program.

Representative PRICE. If there are no further questions, I want to close this meeting and to express our deep appreciation to Admiral Rickover and his organization, Mr. Geiger and his organization, and the Westinghouse people for this fine presentation. I don't see any

of the Westinghouse people here so I hope someone will convey our appreciation to them for this very kind reception to the committee. I think this has been most helpful and informative. I hope in the future our committee can get out to some of these installations and hold official meetings right on the scene while the problems are still fresh in our minds and cause us to raise questions, the answers to which will be helpful to the whole committee.

Chairman DURHAM. Mr. Chairman, I concur in your words. I was at Bettis with a former chairman in 1947, I believe—certainly in 1948—when we first broke ground. When you see such a plant as this today and the accomplishments which have developed since that time, you feel like your money has been spent for something worthwhile.

Mr. FIELDS. Mr. Chairman, may we say we appreciate your coming here and doing this. It is a boon to our morale and that of the people here to see such an interest. I am sure it will be useful to all of us. I hope you can do it other places too. It is most effective.

Representative PRICE. Our thanks to all of the people who testified here today. The committee will stand adjourned.

(Whereupon at 5:05 p. m. the meeting was adjourned.)

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